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Impact of major climate variables on crop agriculture and local adaptation strategies in southeast coastal region of Bangladesh

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Advisor: Professor Jun Sasaki

Co-Advisor: Associate Professor Mayumi Fukunaga

Hassan Faisal

Abstract

A changing climate has both positive and negative impacts on crop production and farmers' adaptation to reduce the negative impact is also crucial in order to maintain sustainable agricultural production. Considering the above phenomena, the study investigated the regional climate variability using descriptive statistics and linear trend model with a 30-year data set of the agro-climatic variables from 1985 to 2014 in the south-eastern coastal region of Bangladesh. Besides, it explored mainly the crop yield and climate relationship using ordinary least square multiple regression considering basic regression assumptions and non-climatic trend removal technique. Finally, the causes of cropping pattern change, local adaptation measures and its significant determinants using multinomial logit (MNL) model with a farm level micro data of 400 farm households obtained from the questionnaire survey were assessed here.

The linear trend model disclosed the evidence of changing climate over the last three decades in the region. The multiple regression models revealed that all five crop models were significant at 5% level except groundnut which was significant at 8% level and climate variables have significant effects on crop yields but the effects vary among different crops. More definitely, maximum temperature and minimum temperature negatively influenced the yield of Boro and Aman rice, respectively. Rainfall significantly favored the yield of Boro rice while affected the yield of Aman rice, pulse and groundnut though insignificantly. Moreover, relative humidity and sunshine exhibited significant negative effect on Boro rice and groundnut consecutively. The R^2 values indicated that three rice crops, such as Aman (42.1%), Boro (52.2%) and Aus (53.8%), were greatly influenced by climate variability and change compared to other major crops in the study area.

Questionnaire survey results revealed that farmers' perception on climate change was consistent with time series analysis of climate data and climate change had significant impact on cropping pattern with some non-climatic contributions. Findings from the MNL model indicates that household size, livestock ownership, tenure status, farm size, climate information, access to credit, distance to market, education and nonfarm income are statistically significant determinants of farmers' adaptation choices. The major barriers to adaptation include lack of knowledge concerning appropriate adaptation measure, inadequate irrigation facilities, insufficient credit facilities, unavailability of climate information on time, lack of land ownership, etc.

By taking into account the effect of climate variables on major food crops, the development and implementation of drought tolerant varieties, particularly for Boro and Aman rice, expansion of flood tolerant varieties for Aman rice and extension of irrigation facilities more intensively particularly for Boro rice have been recommended as some policy implications for the region. Moreover, Government should also target improving the significant determinants to strengthen farmers' adaptation by taking necessary policy measures and thereby, reducing vulnerability to climate change.

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List of Abbreviations and Acronyms

ADF: Augmented Dickey Fuller

AEZ: Agro Ecological Zone

ANOVA: Analysis of Variance

Apr: April

Aug: August

BBS: Bangladesh Bureau of Statistics

BINA: Bangladesh Institute of Nuclear Agriculture

BLUE: Best Linear Unbiased Estimator

BMD: Bangladesh Meteorological Department

BRRI: Bangladesh Rice Research Institute

BWDB: Bangladesh Water Development Board

CDMP: Comprehensive Disaster Management Program

CLM: Classical Linear Model

cm: centimetre

CO_2: Carbon Dioxide

Coef: Coefficient

CV: Coefficient of Variation

DAE: Department of Agricultural Extension

Dec: December

df: Degree of Freedom

DOE: Department of Environment

E: East

EC: Electrical Conductivity

FAO: Food and Agriculture Organization

FGD: Focused Group Discussion

FGLS: Feasible Generalized Least Square

GCM: General Circulation Model

GDP: Gross Domestic Product

GOB: Government of Bangladesh

H_0: Null Hypothesis

H_a: Alternative Hypothesis

HadCM: Hardly Centre Coupled Model

hrs: Hours

HYV: High Yielding Variety

I(0): Integration of Order Zero

I(1): Integration of Order One

IIA: Independence of Irrelevant Alternatives

IPCC: Intergovernmental Panel on Climate Change

Jan: January

K1: Kharif-1

K2: Kharif-2

Kg: Kilogram

LM: Lagrange Multiplier

LMREF: Lower Meghna River and Estuarine Floodplain

LR: Likelihood Ratio

Mar: March

Max: Maximum

Maxt: Maximum Temperature

Min: Minimum

Mint: Minimum Temperature

MLR: Multiple Linear Regression

mm: Millimetre

MNL: Multi Nomial Logit

MNP: Multi Nomial Probit

MOEF: Ministry of Environment and Forest

MSE: Mean Squared Error

N: North

nd: No Date

Nov: November

NS: Not Significant

OLS: Ordinary Least Square

P level: Probability (significance) level

RRR: Relative Risk Ratio

SD: Standard Deviation

Sig: Significant

SPSS: Statistical Package for Social Sciences

SRDI: Soil Resource Development Institute

Temp: Temperature

TNAU: Tamil Nadu Agricultural University

USA: United States of America

VIF: Variance Inflation Factor

WARPO: Water Resources Planning Organization

WB: World Bank

Chapter One: Introduction

1.1 Background of the study

Climate change is already shaping the livelihood and lifestyle pattern of people globally and will continue to do so for generations to come. Agricultural sector is particularly vulnerable to climate change and it has been estimated that climate change will impact negatively on agricultural production in the 21st century through higher temperatures, more variable rainfall and extreme climatic incidents such as floods, cyclones, droughts and rising sea levels (Molua, 2002; Isik and Devadoss, 2006; IPCC, 2007a; IPCC, 2014a; WB, 2010). This susceptibility of agriculture to climate change has led the scientific community and policy makers to investigate the ability of farmers to adapt (Reid et al., 2007; Mertz et al., 2009).

Bangladesh is one of the most vulnerable countries to climate change. Impacts of climate change have already been felt through increasing temperatures, variable rainfall and climate related extreme events, such as floods, droughts, cyclone, sea level rise, salinity intrusion and river erosion (Asaduzzaman et al., 2010; Yu et al., 2010; Hossain and Deb, 2011). Crop agriculture in Bangladesh is one of the most vulnerable sectors to climate change and climate related events (Table 1.1 and Figure 1.1).

The major causes for its vulnerability are (i) its geographic position in the tropics, (ii) its huge area of floodplains, (iii) its low altitude from mean sea level, (iv) its high population density and (v) its extreme poverty level. Nevertheless, it also has inadequate adaptive capabilities due to poor economic condition and limited technological knowledge (MOEF, 2005; DOE, 2007; Shahid and Behrawan, 2008; Pouliotte et al., 2009; Hossain and Deb, 2011). Despite the condition of Bangladesh as a country that is highly vulnerable to climate change, factual studies of the significance of climate change on major food crops have been very limited (Rashid and Islam, 2007). Bangladesh is mainly an agricultural country. Agriculture contributes 16.33% of the total GDP in 2013-14 fiscal year and major portion of the country's labor force, about 47.5% engages in agriculture (Bangladesh

Economic Review, 2013). The socio-economic progress and the advancement of peoples' life quality in Bangladesh is closely interlinked with agriculture. This type of study about climate change impact on the country's agriculture has secured recent attention, due to the contribution of the sector to Bangladesh economy.

Table 1.1: Intensity of the impact of climate change on different sectors (MOEF, 2005).

Vulnerable Sectors	Physical vulnerability context (climate change and climate events)							
	Extreme temperature	Drought	Flood		Cyclone and storm surges	Sea level rise		Soil erosion
			River flood	Flash flood		Coastal inundation	Salinity intrusion	
Crop agriculture	***	***	*	**	***	**	***	-
Fisheries	**	**	**	*	*	*	*	-
Livestock	**	-	-	**	***	**	***	-
Infrastructure	*	-	**	*	*	**	-	***
Industries	**	-	**	*	*	***	**	-
Biodiversity	**	-	**	-	*	***	***	-
Health	***	-	**	-	**	*	***	-
Human settlement	-	-	-	-	***	-	-	***
Energy	**	-	*	-	*	*	-	-

Notes: ***= severely vulnerable, ** = moderately vulnerable, *= vulnerable, - = not vulnerable

http://www.rsc.org/chemistryworld/2015/04/salty-soil-bangladesh-crop-production-climate-change

Figure 1.1: Impact of climate change on Bangladesh agriculture.

It is universally accepted that the effect of climate change on crop yield varies among crops and across regions. The same is also true for Bangladesh agriculture. Noted that the national level data might not represent the real scenario for different agro-ecological regions of any country about climate change impacts on agriculture (Lobell and Field, 2007). This mandates area (region) and crop specific investigation to visualize a total scenario of climate change impact. It may also provide a pathway for policy makers to formulate area specific adaptation strategies which will ultimately remit the adverse effects more effectively (Sarker, 2012).

It is also reported that there is notable regional distinction in case of availability of net cultivable land, cropping intensity, cropping pattern, distribution of farm household and its change over times and growth of GDP in agricultural sector in Bangladesh (Rahman and Zaman, 2013).

Coastal region is designated by a number of unique features, which differ from the rest of the country's physical, hydrological and morphological characteristics and ecosystem (Barkat and Zaman, 2009). The principal features of the coastal region are as follows:

- Presence of numerous islands in the river and sea;
- Large number of rivers and tributaries which flow across the region;
- Abundant flow of water throughout the year;
- Tides exhibit more regular patterns of change and having strong influence on the coastal area and the livelihood of the people;
- Frequent tropical cyclones and storm surge are the main source of destruction;
- The exposed coast is more vulnerable to the natural calamities and
- Tidal surge often inundate huge land area carrying saline water on the coastal land and thereby affect cultivation which is the main source of livelihood of the people.

The coastal region incorporates about 20% of the country and over 30% of the net cultivable area and around 33% population of Bangladesh. Agricultural land use in the region is very limited, which is approximately 50% of the national average (Petersen and Shireen, 2001). Historically, the south-east coastal region of Bangladesh has been hit by cyclones, including two major cyclones in 1970 and 1991 which causes death of 500,000 and 150,000 people, respectively. They also cause innumerable death of livestock and widespread damage to crop and properties (Khalil, 1992). All of the above features of coastal region along with some manmade influences have pronounced impact on agriculture (Rahman and Zaman, 2013).

A wide array of adaptation options have already been practiced by the farmers to reduce the impact of climate change on agriculture in Bangladesh. But the strategies are not enough to cope with the changing climate. So, additional large-scale adaptation currently occurring is needed to reduce the vulnerability to future climate change (IPCC, 2007b). Many factors or determinants that affect farmers' adaptation choices due to climate change include different household, socio-economic, institutional and environmental factors. The knowledge of these household, socio-economic, institutional and environmental factors assists policy makers to strengthen adaptation through investing on these significant factors. More specifically, it is said that adaptation and mitigation choices are context driven and change from area to area and over time (IPCC, 2014b; Smit and Wandel, 2006). This necessitates the country or area based investigations of climate change adaptation strategies. In this regard, very few research studies have been conducted in Bangladesh (FAO, 2006; Rashid and Islam, 2007).

At the same time, a limited number of studies were performed regarding the effect of climate change on crop agriculture (Rashid and Islam, 2007), most of which focused mainly on rice crops at the national level. This is the first study of its kind considering other major crops like pulse and groundnut beside rice at regional level. In addition, there is only one study available about the determinants of rice farmers' adaptation strategies in Northern Bangladesh (Sarker et al., 2013). The study, however, considered only rice farmers and conducted in a drought prone area. Coastal region is different from drought prone region in context of climate and adaptation options.

1.2 Objectives of the study

This study is basically conducted in two aspects: climate change impact on crop agriculture and farmers' adaptation methods, both of which are closely interlinked. Firstly, climate variability in a regional scale and the relationship between major agro-climatic variables were investigated. Secondly, the causes of cropping pattern change and farmers' adaptation strategies and its significant determinants were assessed. The overall objective of the study is to assess the impact of change in climate variables on major crops' yield and identify the significant determinants of local farmers' adaptation choices in the south-eastern coastal region of Bangladesh. To achieve the above two main objectives, the following specific objectives must be fulfilled:

(1) To analyze the trend in climate variables in the aforesaid region;

(2) To assess the impact of five major climate variables, such as maximum and minimum temperature, rainfall, humidity and sunshine duration on the yield of five major crops, namely Aus, Aman and Boro rice, groundnut and pulse;

(3) To find out causes of cropping pattern change in the region;

(4) To find out feasible adaptation measures and barriers in adopting them;

(5) To identify the prime determinants that affect local adaptation choices by using Multinomial Logit (MNL) Model.

1.3 Literature review

1.3.1 Climate change in Bangladesh

According to the IPCC (2007a), climate change refers to any alteration or changes in major climatic variables over a long time. Main causes of these changes are either natural variability or human activities. Bangladesh has a tropical monsoon climate with four distinct seasons (Brammer, 2002): (a) Pre-monsoon (March–May); (b) Monsoon (June–September); (c) Post-monsoon (October–November); and (d) Dry or winter season (December–February).

The country has been experiencing higher temperatures over the last three decades (Sarker et al., 2012). Furthermore, it is forecasted to undergo an increase in annual mean temperatures of 1.0 °C by 2030, 1.4 °C by 2050 and 2.4 °C by 2100 (Ahmed, 2006; Agrawala et al., 2003).

In addition, the General Circulation Model (GCM) data estimated more warming for winter than for the summer months (FAO, 2007). Based on the above forecast, Bangladesh will experience further warm days and heat waves, longer dry period and higher drought risk. In contrary, about 80% of rainfalls in Bangladesh is observed during monsoon season. Although rainfall during monsoon season is forecasted to rise; the rainfall variability could rise considerably producing more intense rainfall and or prolonged dry periods. Most of the climate models projected that rainfall will increase during the summer monsoon (Mirza, 1997; Ahmed and Alam, 1998; GOB, 2009).

Mondal and Wasimi (2004) investigated the temperatures and rainfalls of the Ganges Delta within Bangladesh and observed a rising trend of 0.5 °C and 1.1 °C per century in day-time maximum and night-time minimum temperatures, respectively. They also found a rising trends in winter, pre-monsoon and summer rainfalls.

WARPO (2006) projected that 14, 32, and 88 cm sea level rise will occur in 2030, 2050 and 2100, respectively, which may submerge approximately 8, 10 and 16% of the country.

Islam and Neelim (2010) examined the maximum and minimum temperatures of four months (January, April, May and December) and two seasons. The months of April-May were considered as the summer season and the months of December-January as the winter season. The findings of the study revealed an increasing trend in both summer and winter temperatures.

CDMP (2012) studied temperature (1948-2010) at 34 locations of Bangladesh and found an overall increasing trend of about 1.2 °C per century for all-Bangladesh annual temperatures. The study also explored an increasing trend of 2.4 °C per century for recent mean annual temperatures (1980-2010), almost the double of the longer-term trend. Moreover, it examined sunshine duration data and found a decreasing trend of 5.3% per decade for all-Bangladesh sunshine hours. Further, the study revealed a significant increasing trend of 1.0% and 1.1% per decade for pre-monsoon and winter humidity, respectively. The recent (1980-2010) trend of humidity observed to be much higher than the long-term (1948-2010) trend. Considering the above literature, it is evident that the climate of Bangladesh has changed significantly in recent times.

1.3.2 Impact of climate change on crop agriculture

1.3.2.1 World agriculture

Global agricultural production is expected to be seriously affected by climate change. This will happen because agricultural yield is mostly dependent on climate and is negatively impacted by increasing anthropogenic climate change and climate variability (IPCC 2007a; Chandrappa et al., 2011).

A lot of research outlined that rising temperatures, variable rainfall, intense floods, droughts and cyclones would result in a considerable decrease in global food production, particularly in developing countries (Parry et al., 1999; Gregory et al., 2005). Climate change influences agricultural production directly through changes in agro-ecological conditions and, thus, affects total food supply (Gregory et al. 2005; Ingram et al., 2008). The overall effect of climate change on food security varies across regions and over time (Misselhorn, 2005; Stern, 2006).

Rosenzweig and Parry (1994) analyzed the probable impact of climate change on global food supply using a crop growth model. It was found that climate change impacted developed and developing countries differently. Countries in the lower latitude regions (i.e., developing countries) will encounter the utmost brunt of the problems caused by climate change. Parry et al. (1999) investigated the probable impacts of climate change on crop yields, global food supply and hunger risk using the Hardly Centre Coupled Model (HadCM2) global climate change model scenarios. It was found that the outcomes for crop yields are beneficial for countries in mid and high latitude regions (i.e., the developed world) while the effects are harmful for countries in low latitude regions (i.e., the developing world, excluding China).

Mendelsohn et al. (1994) studied that the USA's agriculture would potentially gain from climate change. The study also estimated a 1% rise in agricultural GDP under a CO_2 doubling scenario. But Schlenker et al. (2005) found negative impacts on US agricultural production of approximately $5.3 billion annually. Reinsborough (2003) investigated that Canadian agriculture would be impacted by climate change negligibly in the next three decade. Employing district level data, Lippert et al. (2009) showed some benefits resulting from recent climate change for German agriculture. The agreement is that climate change is unlikely to impact developed countries' agriculture negatively over the rest of the century.

Due to the size of the sector, its climate susceptibility and the geographical location of developing countries in the lower latitudes of the world, crop agriculture in developing countries is expected to be affected greatly (IPCC, 2007a). Lansigan et al. (2000) studied that climate change is very likely to impact rice production in Philippines. Using district level data, Sanghi and Mendelsohn (2008) revealed that climate change is likely to cause adverse impact on agriculture of Brazil and India by 2100. In a study at the International Rice Research Institute, Peng et al. (2004) found a 10% decrease in rice yield per 1 °C increase in growing season night temperature. In Ethiopia, Deressa and Hassan (2009) investigated that climate variables would affect crops notably. Although, adaptation measures will be able to lessen the impact. Moula (2009) determined the impact of climate change on Cameroon smallholder agriculture using national field level data and revealed that crop yield was more sensitive to rainfall than temperature and a higher temperature was also damaging to agricultural output. Wang et al. (2009) studied the effects of rainfall and temperature on crop net revenue both for rain-fed and irrigated farms in China, and showed that climate change was harmless for irrigated farms but damaging for rain-fed farms. Moreover, higher temperatures mostly affect crop revenue adversely. But the impacts are not the same across the regions of China.

1.3.2.2 Bangladesh agriculture

The changing and irregular distributed pattern of climate variables creates drastic climate events like floods and droughts, which have striking harmful impact on agricultural crops' yield, particularly on Aman rice. Consequently, rice yield will reduce by 8%–17% by 2050 (BBS, 2005; IPCC, 2007a; Sarker, 2012).

Ali (1999) studied that sea level rises in eastern Bangladesh will result in the reduction of huge agricultural land mainly exacerbated by beach erosion. But he did not determine the effects of temperature, rainfall, humidity and sunshine on the coastal area's agriculture production and output. Rashid and Islam (2007) recognized drought, flood, soil salinity and cyclone as the major severe climatic incidents which affected crop cultivation and production seriously.

Rimi et al. (2009) studied the impacts of climate change on rice production. Findings revealed that temperature variations have striking effect on crop yield. The summer rice crop, Aus yield declined considerably while Boro yield, a winter rice crop, increased notably with the rise of minimum temperature. Rahman and Parvin (2009) investigated that Aman rice is the dominant crop in Bangladesh from 1980–1981 and represents about 57% of the total share. But, due to extreme climatic incidents, the share of Aman rice to the overall rice production reduced to 40% by 2005–2006, even though the total farming area allocated to this crop is much larger than others to date.

Climate Change Cell (2009) estimated that the rice yield could decline by 15-20% due to a decrease in day length of 25%. Hossain and Teixeira da Silva (2013) studied that global warming is expected to severely reduce the yield of various crops, including rice and wheat in Bangladesh.

Sarker (2012) performed a study to investigate the relationship between three climate variables, such as maximum temperature, minimum temperature and rainfall and three rice crops at the country level. He accounted 1984–1985 financial years' yield as the yield of 1985. Nevertheless, to maintain uniformity between climate variables and yield, he considered 1985's climate for 1985's yield. In reality, the previous (1984) year's climate data should be computed for Aus and Aman rice as their growing season entirely fall in this year. For computing climate data of Boro rice, two calendar years should be merged into one (for instance, from December of 1984 to May of 1985 for 1985's yield), as he accounted the growing months of Boro rice to be December-May. Therefore, his study might not depict the actual relationship between climate change and crops yield. Moreover, he did not inspect relative humidity and sunshine duration as major climate variables although these variables have considerable effect on crop agriculture.

Amin et al. (2015) investigated the relationship between five climate variables and three rice and one wheat crop at the national level and found that maximum temperature, rainfall and humidity had significant impact on different crops' yield.

As a whole, the effect of climate change differs between and within AEZs of the same country (Gbetibouo and Hassan, 2005). Hence, there is an opportunity for further country or area specific research with particular attention to individual crops or livestock (Mariara et al., 2007). Furthermore, some of the findings from previous studies are not concrete because of inadequate statistical and diagnostic tests (Sarker, 2012).

1.3.2.3 Reasons of choosing statistical method:

Many studies on the probable effects of climate change on crop yields employed indirect crop simulation models that make use of crop biophysical simulation. There are comparatively finite number of studies based on regression models (Boubacar, 2010; Mendelsohn, 2009; Peng et al., 2004). Crop simulation type of study will give us the understanding of physiological effects of high temperature on crop yield but not the effects of small rise in temperature related with global warming (Schlenker and Roberts, 2008). In addition, though it is unambiguous that global warming is inevitable in the coming century, even if emission of green-house gases is maintained at present level, there remains argument and question mark on the magnitude of warming as well as other related changes (IPCC, 2013; Rosegrant et al., 2008). Therefore, predictions of the yield changes in response to changes in climate variables, from regression models on the basis of historical climate and yield data for particular crops are relatively reliable (Boubacar, 2010; Isik and Devadoss, 2006; Lobell and Field, 2007).

1.3.3 Causes of cropping pattern change

Cropping pattern generally means the proportion of area under different crops at a point of time, whereas change in cropping pattern refers to the change in proportion of area under different crops at two different points of time (Punithavathi and Baskaran, 2010). There are many studies in literature relating to the identification of cropping pattern and its changes. But very few among them considered the causes of cropping pattern change especially in climatic context and using empirical data. The cropping pattern of an area mainly depends on agro-climatic, technological and institutional factors (Vaidyanathan, 1992). More accurately, the cropping pattern is controlled by the law of relative advantage in relation to agro-climatic conditions (De, 2002). Gunarathna et al. (2004) studied the effect of rainfall on cropping pattern in Hambantota District of Sri Lanka using historical rainfall data and questionnaire survey. The study revealed that change in the onset and magnitude of rainfall results in the change of crop cultivation and crop commencement week. Using a regional bioclimatic model, Krishnan (n.d.) found that the climate changes affect the existing cultivating areas, including cropping pattern in Tamil Nadu, India, due to unscheduled rainfall, high temperature, high tensed cyclones and so on. Ahmed et al. (2016) explored that increase in agricultural land use is primarily climate-driven in the western part of West Africa and socioeconomically driven in the eastern part. Therefore, it is hypothesized in the study that cropping pattern change is governed by both climatic and non-climatic factors.

1.3.4 Adaptation to climate change in agriculture

1.3.4.1 Importance of adaptation

Adaptation to climate change is delineated as an adjustment in natural or human systems in response to actual or potential climatic stimuli or their effects (Smit et al., 1999). More specifically, adaptation refers to all those responses to climate change that can be used to reduce vulnerability or to actions devised to take advantage of new opportunities that may occur as a result of climate change (Burton et al., 1996). Adaptation is a policy option to reduce the negative impacts of climate change (Kurukulasuriya and Mendelsohn, 2008). These actions maintain, preserve or improve the viability of agricultural production (IPCC, 2001). Adaptation to climate change is the key to nullify the potential adverse impacts of climate change (Mariara et al., 2007; Stern, 2007; Hassan and Nhemachena, 2008). Because it can secure poor farmers' livelihood by ensuring food security (Bryan et al., 2009).

1.3.4.2 Farmers' adaptation options and barriers to adaptation

The most conventional type of adaptation options in agriculture incorporates changing crop varieties, planting trees, diversification of crop and livestock, soil conservation, changing planting date, increasing plant spacing, farming of non-rice crops, planting short duration crop, more irrigation, agroforestry and homestead gardening, etc. (Kurukulasuriya and Mendelsohn, 2008; Bryan et al., 2009; Deressa et al., 2009; Sarker et al., 2013).

Even though farmers' have recognized or perceived climate change, many farmers are unable to make any change or adjustments to their farming system. The major barriers to adaptation involve lack of information, lack of access to credit and land, lack of irrigation facility, labor shortage and lack of market access, etc. (Bryan et al., 2009; Deressa et al., 2009; Sarker et al., 2013). Accordingly, farmers' adaptation measures mainly depend on their own resources.

1.3.4.3 Determinants of adaptation choices

Mainly three type of factors affect farmers' adaptation choices: household characteristics, institutional factors and social capital. Household characteristics involve age, education, gender, household size, farm size, farming experience and wealth (Kurukulasuriya and Mendelshon, 2008; Bryan et al., 2009). Institutional factors contain access to extension services, climate information, access to credit, non-farm income opportunities and land tenure status (Hassan and Nhemachena, 2008; Deressa et al., 2009; Gbetibouo, 2009). Social capital incorporates farmer-to-farmer extension and the number of relatives nearby (Deressa et al., 2009). These variables all affect the farmers' choice of adaptation strategies. According to the literature, different factors or determinants have distinct impacts on farmers' choice of adaptation to climate change.

The gender of the household head governs adaptive choices at the farm level. Some recent studies revealed that male-led households have more adaptive capacity than female-led households (Asfaw and Admassie, 2004; Bryan et al., 2009; Deressa et al., 2009).

Evidence from various sources confirmed a positive association between the education level of the household head and the acquisition of improved agricultural technologies (Lin, 1991) and adaptation to climate change (Maddison, 2006). As a result, farmers with higher education level are more likely to adapt better to climate change.

The age of the head of the household is an important factor or determinant affecting farmers' adaptation choices. However, the direction of the association varies in the literature. There exists a positive relationship between age and farmers' choice of adaptation (Hassan and Nhemachena, 2008; Gbetibouo, 2009) while a negative relationship between the variables is also observed in some studies (Anley et al., 2007; Nyangena, 2008). This study analyzes the hypothesis that age and experience are likely to increase the probability of adaptation to climate change.

The relevant literature supports that farm size has both positive and negative effects on adaptation (Bradshaw et al., 2004). As farm size is related to greater wealth acquisition, the present study examines the hypothesis that farm size is likely to increase adaptation to climate change.

Having a higher labor endowment, large household size is more likely to adapt better to climate change (Deressa et al., 2009) because households with large family may be pushed to transfer part of the labor force to non-farm income activities in an attempt to earn extra income in order to abate the consumption pressure (Yirga, 2007) and are more likely to implement agricultural technology and utilize it more effectively because they have fewer labor deficits at peak times (Croppenstedt et al., 2003). So, this study investigates the hypothesis that households with large family are more likely to adapt to climate change.

Farm and nonfarm income exhibit wealth. It is frequently hypothesized in the literature that the implementation of agricultural technologies need sufficient financial capabilities (Knowler and Bradshaw, 2007). A positive association between income and adoption level is also revealed from some other studies (Franzel, 1999).

Agricultural extension and climate information represent access to the information required to take the decision to adapt to climate change. Several studies in developing countries document a strong positive relationship between access to information and adaptation to climate change (Maddison, 2006; Nhemachena and Hassan, 2007). As a result, this study also analyzes the hypothesis that access to information strengthens adaptation to climate change.

By serving as a store of value and by providing traction (particularly oxen) and manure necessary for soil fertility improvement, livestock plays a very crucial role in strengthening farmers' adaptation choices (Yirga, 2007). Therefore, the present study examines the hypothesis that livestock ownership increases the likelihood of adaptation to climate change.

Availability of credit remits the cash constraints and enables farmers to purchase agricultural inputs, such as fertilizer, improved crop varieties, and irrigation facilities.

Previous studies demonstrate that there remains a positive relationship between the adaptation level and the availability of credit (Yirga, 2007; Hassan and Nhemachena, 2008; Deressa et al., 2009). Similarly, this study also analyzes the hypothesis that there is a positive association between availability of credit and magnitude of adaptation.

It is commonly hypothesized that adaptation to climate change decreases as distance to output and input markets increases. Proximity to market is a significant determinant of adaptation, presumably because the market acts as a place of exchanging information including new technology (Maddison, 2006).

Social capital can be described by the number of relatives of a household in a particular area and farmer-to-farmer extension. In general, informal institutions and private social networks serve three important roles in strengthening farmers' adaptation (Katungi, 2007). Firstly, it serves as a channel of financial transfers that can ease the farmer's credit problems. Secondly, it can act as conduits for information about new technology. Thirdly, in the case where the adoption of technologies incorporates externalities, social networks can expedite collaboration and partnership to overcome collective action dilemmas. Therefore, the study analyzes the hypothesis that social capital is likely to increase the probability of adapting to climate change.

1.3.4.4 Selection of MNL model for analyzing the determinants of adaptation strategies (Hassan and Nhemachena, 2008; Deressa et al., 2009; Sarker et al., 2013)

Although both agro-economic and Ricardian cross-sectional models generally include some adaptation issues, these two strategies are not able to estimate the determinants of farmers' adaptation choices (Gbetibouo and Hassan, 2005; Deressa and Hassan, 2009). Logit and probit models are commonly used for investigating the adoption of adaptation in agriculture. When the number of adaptation options that farmers practice limited to two alternatives, binary logit and probit models are used. An extension of these models, called multinomial logit (MNL) and multinomial probit (MNP) models, are employed when the number of adaptation options is more than two. Noted that a number of adaptation choices are implemented by farmers, the appropriate econometric model would be either a MNL or a MNP. These two models examine the effects of independent variables (factors or determinants) on a dependent variable (choice of adaptation) with multiple choices in an unordered way. Both models have been applied in some recent climate change adaptation studies (Nhemachena and Hassan, 2007; Deressa et al., 2009; Hisali et al., 2011). The MNP model was used to analyze the determinants of farmers' adaptation strategies in Southern Africa by Nhemachena and Hassan (2007). Deressa et al. (2009) employed the MNL model to determine the factors that affect farmers' adaptation choices in the Nile Basin of Ethiopia. Hisali et al. (2011) also applied the MNL model to assess factors influencing farmers' adaptation options in Uganda. A recent study by (Sarker et al., 2013) used the MNL model to assess the determinants that affect rice farmers' adaptation strategies in Northern Bangladesh. As the MNL model is simple in computation, it is largely used in compared to the MNP model (Tse, 1987). Due to the complexity involved in its estimation process, MNP model is not used widely (Cheng and Long, 2007). Therefore, MNL model is selected for analyzing the determinants of farmers' adaptation strategies.

Chapter Two: Materials and Methods

2.1 Study area

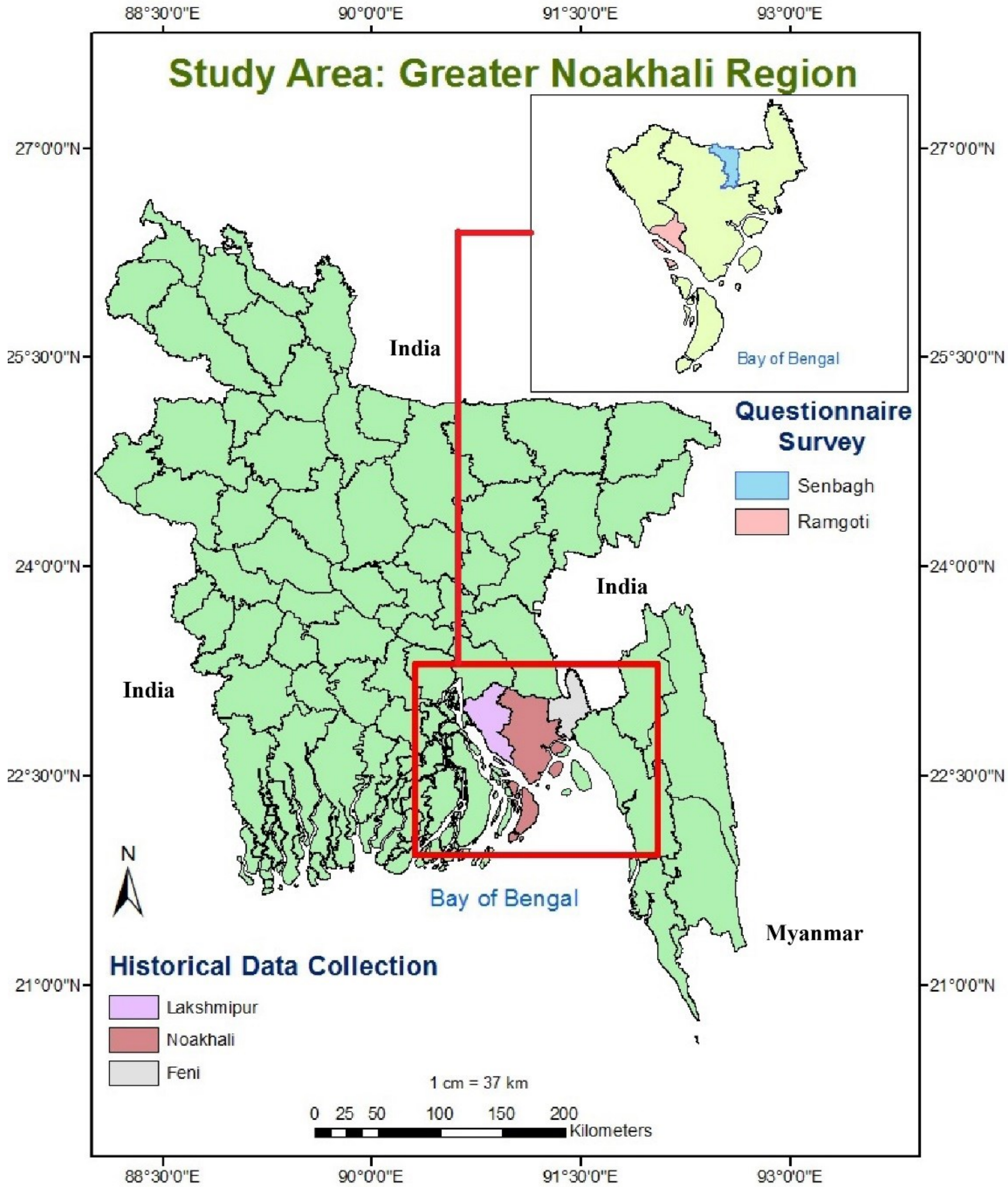


Figure 2.1: Location map of Greater Noakhali Region situated at the south-eastern part of Bangladesh and locations of questionnaire survey area.

The present study was carried out in Greater Noakhali area, the south-east coastal region of Bangladesh (Figure 2.1). The region is located between $22^0 0'$ N to $23^0 17'$N latitude and $90^0 38'$ E to $91^0 35'$ E longitude and consists of 3 districts namely Noakhali, Lakshmipur and Feni with an area of 6586 sq. km and 67,88,780 population (Population census, 2011). Climate change already affected the region and its agriculture severely by extreme climatic incidents such as salinity intrusion, cyclone, river bank erosion, flood, drought, etc. Moreover, the region experienced 18 of total 59 major cyclones that hit Bangladesh coast (Khan, 2013).

2.1.1 Agriculture in Greater Noakhali Region:

Greater Noakhali, a typical agricultural region, represents an agro-ecological zone called Lower Meghna River and Estuarine Floodplain (LMREF). Agriculture mainly determines the livelihood and lifestyle pattern of the people living in the region. Aus, Aman and Boro rice, pulse, groundnut, vegetables, green chili, sweet potato, mustard, wheat, etc. are major food crops in the region which grown in 3 distinct growing seasons namely Kharif-1, Kharif-2 and Rabi. The region holds a distinct environmental features and agro-ecological conditions. About 78 thousand hectares of land has already been affected by salinity at different levels. Moreover, 39,652 hectares of land is also affected by water logging problem mainly due to siltation and poor drainage capacity (FAO, 2016). The cropping intensity in the region is much lower than those of non-saline areas of the country (Shahidullah et al., 2006). As a result, agricultural development in the region is slow and unbalanced over the space (Quddus, 2009).

2.1.2 Growing seasons of major agricultural crops in Greater Noakhali Region

The season of the year when a specific crop is generally grown is the growing season of that crop. It specifies the distribution of crops in a year on the basis of climatic requirement as different seasons are characterized by different climatic characters that normally affects crop germination, growth, flowering and finally yield. In general, three distinct cropping or growing seasons prevail in Bangladesh (DAE, 2015). The same growing seasons are also followed by farmers of the region. Major crops grown in those seasons are shown in Table 2.1.

Characteristics of growing season (Hasanuzzaman, 2008)**:**

Kharif-1 is characterized by initial attack by drought; high incidence of disease, insect and weed due to high temperature and humidity; low photosynthetic rate due to cloudy sky;

Table 2.1: Growing seasons of major crops in Greater Noakhali Region.

Growing Season	**Rabi**	**Kharif-I**	**Kharif-II**
Duration	Mid-October To Mid-March	Mid-March To Mid-July	Mid-July To Mid-October
Major Crops	Boro Rice, Pulse, Groundnut, Soybean, Winter Vegetables, Sweet Potato, Green Chilli, Mustard, Wheat	Aus Rice, Summer Vegetables, Jute, etc.	Aman Rice,

effect of natural disaster in the latter stage, e.g. flood, storms, etc.; short life span of the crop in compared to other season; lodging effect due to storm.

Kharif-2 is characterized by comparatively lower temperature and respiration than Kharif-1; higher photosynthetic rate than Kharif-1; less incidence of disease, insects and weed attack; less cloudy sky and higher life span of the crop than Kharif-1.

Rabi is characterized by higher net photosynthesis than other seasons due to low temperature and shiny sky; low respiration rate than others due to low temperature; less weed infestation; no lodging effect, etc.

2.1.3 Climatic features of major agricultural crops in Greater Noakhali Region

Three rice crops (Aus, Aman and Boro), pulse and groundnut are the major agricultural crops in Greater Noakhali region. These five food crops are grown in three distinct seasons. Aus rice is normally sown in March–April and harvested in July–August. Aman rice is generally planted in June-August and harvested in November-December. The other rice crop, Boro is transplanted in December-January and harvested in April-May (Amin et al., 2015; Sarker, 2012). Khesari (grasspea), lentil, mungbean, maskalai (black gram), chickpea and cowpea are major pulse crops grown in Bangladesh. Among them, khesari (grasspea), lentil, and chickpea are cultivated during winter (Nov-Mar), and represent more than 75% of total pulse production. Black gram is cultivated during rainy season to early winter (Aug-Dec), while mung bean is planted during the rainy season in the northern parts of the country and during late winter (Jan-Apr) in the southern parts of the country (Rahman et al., 2000). To some extent, the calendar of these major crops slightly varies from area to area, depending on soil and climatic conditions. Pulse crops are normally grown during rabi (winter) season in Greater Noakhali Region. Groundnut is also cultivated during rabi season in the region. According to BRRI (1991), Aus rice requires supplementary water at the primary stage of its growing season while Aman rice is fully dependent on rain that plants in the months of monsoon, although it needs subsidiary irrigation at the time of transplanting and sometimes at the flowering stage subject to the availability of rainfall. Boro is the completely irrigated rice as it grows mainly in the dry winter season (Mahmud, 1997). Though pulse and groundnut can be grown in both irrigated and non-irrigated conditions, these crops are grown particularly under non-irrigated conditions in the study area with residual soil moisture of winter months.

2.2 Data collection method

Data collection framework is shown in Figure 2.2. Thirty years' historical time series data (1985-2014) about cropping area, production and five major climate variables were collected in March, 2015 and 400 farmers' household survey (using semi-structured questionnaire survey) was conducted with 2 FGDs during Mid-August to Mid-October, 2015.

2.2.1 Historical data collection

Historical time series data about cropping area and production of major crops were collected for the period of 1985 to 2014 on fiscal year basis from various official registers and records of three district offices of Department of Agricultural Extension (DAE) located in the region. Because such type of data are only available for the 30 years' period

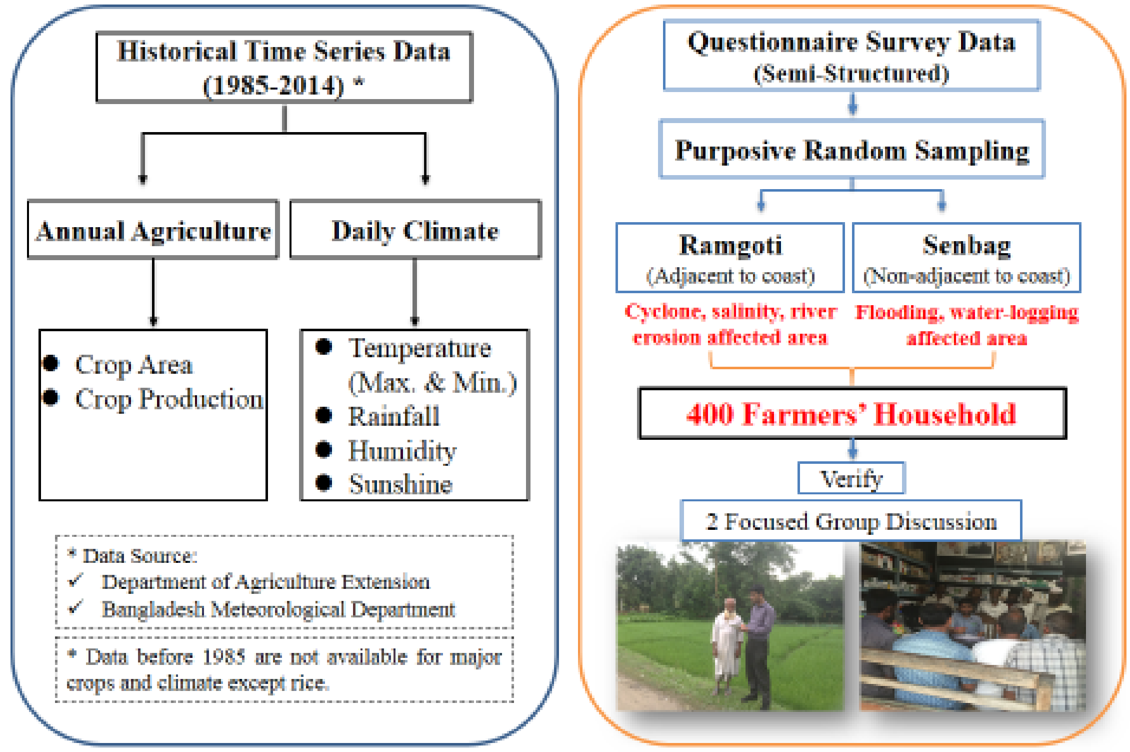


Figure 2.2: Framework of data collection.

and data before 1985 are not available for major climate variables and major crops except rice. Daily data of 5 (five) major climate variables, namely, maximum and minimum temperature, rainfall, relative humidity and sunshine duration for the same period were collected from Bangladesh Meteorological Department (BMD) for the two meteorological stations, namely, Maijdee and Feni of the region. A period of about 30 years or more is qualified to study the impact of climate variables on crop yield in relation to climate change (IPCC, 2007b). Both type of historical data were collected in March, 2015.

2.2.2 Questionnaire survey

A cross sectional farmers' household survey was conducted between Mid-August and Mid-October, 2015 in two coastal sub-districts of the region, namely, Ramgoti (Figure 2.3) and Senbag (Figure 2.4). Based on proximity to the coast, Ramgoti is a coastal sub-district adjacent to the coast while Senbag is a far distant and non-adjacent coastal sub-district. The another main reason of selecting these two sub-districts was that climate change had already influenced the areas seriously as Ramgoti is affected by cyclone, salinity intrusion and river bank erosion problems while Senbag is affected by flood and water-logging problems. Purposive random sampling technique and semi-structured

Figure 2.3: Farmers' survey at Ramgoti sub-district

Figure 2.4: Farmers' survey at Senbag sub-district

questionnaire were used to survey total 400 households of which 200 samples were randomly collected from all unions (the lowest administrative unit) and municipalities of each sub-district. Questionnaire survey data mainly contained farmers' perception about climate change, concept about cropping pattern change and its causes, farmers' adaptation to perceived climate change, factors that affect adaptation choices (i.e., household, socio-economic, institutional factors, etc.), their adjustment in adopting adaptation and barriers to adaptation.

2.2.2.1 Sample size determination

Table 2.2: Description of sample size.

Sub-district	**District**	**Union**	**Farmer Household**	**Sample size**
Senbag	Noakhali	10 (including 1 municipality)	25500	200
Ramgoti	Lakshmipur	9 (including 1 municipality)	32200	200
Total	**Greater Noakhali Region**	**19**	**57700**	**400**

Sample size for the questionnaire survey was determined by following the Yamane method: $n = N / [1 + N (e)^2]$ (Yamane, 1967), where n is the sample size, N is the population size, and e is the level of precision. According to the formula, sample size of 397 is required for the present study. However, 400 samples were collected to avoid fraction and maintain an adequate sample size.

2.2.3 Focused group discussion

Moreover, 2 FGDs, one in each sub-district, were conducted to verify the information provided by household (Figure 2.5). Each focused group consisted of 15-20 people among which individuals from various social groups of the area including local agriculture extension agent, local government agent, educationist, religious leader and experienced farmers were attended. They were asked the same questions as the surveyed households had been questioned beforehand.

Figure 2.5: Focused group discussion at Ramgoti (left-side) and Senbag (right-side).

2.3 Annual and seasonal climatic variation

To identify the changes in climate variables and climate variability over time, descriptive statistics such as simple mean, moving average, minimum, maximum, standard deviation, coefficient of variation, skewness and kurtosis, etc. were measured for annual and growing season climate. Linear trend model was employed to identify the long term trend of annual climate. Moreover, trend graph was constructed for three growing season climate to observe the variations and changes in trend (upward or downward) among five climatic variables over the study period (1985–2014).

2.3.1 Descriptive statistics

2.3.1.1 Moving average

It is a classical method of time series decomposition to estimate the trend cycle. A moving average of order m can be written as

$$\hat{T}_t = \frac{1}{m}\sum_{j=-k}^{k} y_{t+j}$$

where m = 2k+1. That is, the estimate of the trend-cycle at time t is accomplished by averaging values of the time series within k periods of t. Observations that are close in time are also likely to be close in value, and the average removes some of the randomness in the data, leaving a smooth trend-cycle component. This is called an m-MA meaning a moving average of order m (Hyndman and Athanasopoulos, 2013). In case of climate data, a 5 yearly moving average was used to smooth out short-term fluctuations and highlight long term trends.

2.3.1.2 Standard deviation

One of the basic methods of determining variability in climate is to use the standard deviation estimator in measuring dispersion. It is the most robust and widely used measure of dispersion. The sample standard deviation, S_x, is as follows (Waller, 2008):

$$S_x = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(n-1)}}$$

where S_x= the estimator of the standard deviation σ_x of a climate variable X

x = sample mean

n = sample size

x_i = i^{th} observation of a climate variable X.

For any dataset, the closer the value of the standard deviation is to zero, the smaller is the dispersion.

2.3.1.3 Coefficient of variation

The standard deviation as a measure of dispersion is not easy to interpret on its own. Normally, a small value for the standard deviation shows that the dispersion of the data is low and vice-versa. However, the magnitude of these values depends on what is being analyzed. A method to get rid of the difficulty of interpreting the standard deviation is to take into account the value of the mean of the dataset and use the coefficient of variation**.** The coefficient of variation, V_x, is a relative measure of variability and defined as follows (Waller, 2008):

$$V_x = \frac{S_x}{\overline{x}} \times 100$$

Where S_x = standard deviation and $\overline{x}$ = mean or average.

2.3.1.4 Skewness

It determines the degree of asymmetry of a distribution around its mean. Negative values for the skewness indicate data that are skewed left and positive values for the skewness indicate data that are skewed right.

The equation for skewness is defined as (Zaiontz, 2015):

$$\frac{n}{(n-1)(n-2)} \sum \left(\frac{x_i - \overline{x}}{s} \right)^3$$

where $\bar{x}$ is the mean, s is the standard deviation and n is sample size.

2.3.1.5 Kurtosis

It characterizes the relative peakedness or flatness of a distribution compared with the normal distribution. Positive kurtosis indicates a relatively peaked distribution while negative kurtosis indicates a relatively flat distribution. The equation for kurtosis is defined as (Zaiontz, 2015):

$$\left\{ \frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum \left(\frac{x_i - \overline{x}}{s} \right)^4 \right\} - \frac{3(n-1)^2}{(n-2)(n-3)}$$

where $\bar{x}$ is the mean, s is the standard deviation and n is sample size.

2.3.2 Linear trend model

To determine the growth rate of a variable, a simple linear trend model is generally used (Gujrati, 2004). The equation is as follows:

$y = a + bt + \varepsilon$

Where, y = temperature, humidity, rainfall, sunshine duration, etc.;

t = time (year);

a = the intercept;

b = the slope of the linear trend line;

ε = the error term.

2.4 Crop yield-climate relationship

2.4.1 Data arrangement for crop yield-climate relationship

Daily climate data were converted into annual growing season climate data for regression analysis. For example, daily climate data of Mid-March to Mid-July and Mid-July to Mid-October in 1985 were considered as 1985 Kharif-1 and Kharif-2 season while those of Mid-October to December in 1984 and December to Mid-March in 1985 were considered as 1985 Rabi season. Because Rabi season, ranges from Mid-October to Mid-March, falls into two calendar years. On the other hand, cropping area and production data are available on fiscal year basis such as 1984-1985, 1985-1986, etc. as data are recorded in such manner. For instance, cropping area and production data of 1984-1985 Kharif-1 and Kharif-2 were considered as 1984 Kharif-1 and Kharif-2 data while those of 1984-1985 Rabi were considered as 1985 Rabi data, because fiscal year in Bangladesh extends from July in one year to June in the next year. Generally, the life span average had been taken into account for all the climatic parameters except for rainfall. Production period total had been calculated for rainfall. Crop yield data were produced by dividing total production by total area for a specific crop. Moreover, as cropping area and production data were recorded in hectare and metric ton unit respectively, the yield obtained for different major crops were in kg/hectare. Consequently, yield data were converted in to kg/acre to make compatibility with other researchers (Amin et al., 2015; Sarker, 2012). In order to obtain a true crop yield-climate relationship, climate and crop yield data were arranged in such a way so that actual crop production period and corresponding climatic (growing) season merged completely into the same period. Noted that growing season average climate is able to capture the net effect of the entire development process by which crop yields are affected by climate (Lobell and Field, 2007). In addition, growing season average temperature is a major factor that determines average yield (Cabas et al., 2010). Growing season average maximum and minimum temperature and growing season total rainfall were employed in a couple of previous studies (Chang, 2002; Lobell and Field 2007; Lobell et al., 2008). Among the modelled five major crops, Aus rice is grown in Kharif-1, Aman rice in Kharif-2 and Boro rice, Pulse and Groundnut in Rabi season.

2.4.2 Multiple regression model

Multiple linear regression model using OLS (Ordinary Least Square) method with basic regression assumptions and non-climatic trend removal technique (influence of production input, technology, etc.) was employed to determine the crop yield-climate relationship of five major crops for the study period.

The classical multivariate linear regression is an approach for modeling a linear relationship between a dependent variable (also called a response variable) and a set of independent variables (also called independent variables).
The relationship between a dependent variable Y and an independent variable X can be postulated as a linear model (Chatterjee and Hadi, 2006; Sarker, 2012):

$Y = \beta_0 + \beta_1 X + \varepsilon$……………………………….(2.1)

where β_0 and β_1 are the model regression coefficients or parameters and ε is a random disturbance or error term. Y is approximately a linear function of X and ε measures the deviation in that approximation. The coefficient, β_0 is also termed as constant coefficient or intercept and the coefficient, β_1 is called the slope. For each observation of a dataset, the equation (2.1) becomes:

$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i, \quad i = 1,2, \dots \dots \dots \dots \dots, n,$ (2.2) where y_i denotes the ith value of the dependent variable Y, x_i denotes the ith value of the independent variable X, and ε_i denotes the error in the approximation of y_i.

On the basis of available data, the parameters β_0 and β_1 are estimated by employing the least squares method which produced the regression line that minimizes the sum of squares of the vertical distances from each point to the line. The vertical distances denotes the errors in the response or dependent variable. By rewriting the equation (2.2), these errors can be obtained as:

$$\varepsilon_i = y_i - \beta_0 - \beta_1 x_i, \quad i = 1,2, \dots \dots \dots, n. \qquad (2.3)$$

The sum of squares of these distances can then be illustrated as

$$\sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (y_i - \beta_0 - \beta_1 x_i)^2 \qquad (2.4)$$

The values of $\widehat{\beta_0}$ and $\widehat{\beta_1}$ that minimize the sum of squares of the error term are expressed by

$$\widehat{\beta_1} = \frac{\sum (y_i - \bar{y})(x_i - \bar{x})}{\sum (x_i - \bar{x})^2} \qquad (2.5)$$

$$\widehat{\beta_0} = \bar{y} - \widehat{\beta_1}\bar{x} \qquad (2.6)$$

The estimates $\widehat{\beta_0}$ and $\widehat{\beta_1}$ are defined as the least squares estimates of β_0 and β_1 since they are the solution to the least squares method, the intercept and the slope of the line that has the minimum possible sum of squares of the vertical distances from each point to the line. Due to the reason, the line is also defined as the least squares regression line. The least squares regression line can be denoted by

$$\hat{Y} = \widehat{\beta_0} + \widehat{\beta_1} X \qquad (2.7)$$

For multiple linear regression with ^{nth} independent variables (X_1.....X_n), the estimated least squares regression can be written by:

$$\bar{Y} = \widehat{\beta_0} + \widehat{\beta_1} X_1 \dots \dots \dots + \widehat{\beta_n} X_n \qquad (2.8)$$

For a small or medium size sample, FGLS is less efficient than OLS. Therefore, some authors prefer to use OLS (Baltagi, 2008; Greene, 2003). In statistics, a sample size of 30 is generally considered as a medium sample size and a threshold limit. On the other hand, a sample size of more than 30 is regarded as large sample and less than 30 is treated as small sample. As the sample size was medium (30), OLS method was selected to investigate the crop yield-climate relationship. Moreover, OLS is more efficient and preferable when the model does not suffer from heteroskedasticity and autocorrelation. Statistical software package SPSS was used to perform the multiple regression analysis.

2.4.2.1 Basic assumptions of multiple linear regression (MLR):

Basic or classical linear model (CLM) regression assumptions allow OLS to produce estimates $\hat{\beta}$ with desirable properties (Kennedy, 2008). In case of multiple linear regression for time series data, generally five basic regression assumptions are maintained or followed in order to ensure the reliability of the model: stationarity of the data series, no heteroscedasticity (homoscedasticity), no or little multicollinearity, no autocorrelation or serial correlation and approximate normal distribution of the regression residuals.
Under the CLM assumptions, the Gauss-Markov theorem says that the OLS estimator $\hat{\beta}$ is **BLUE**: **B**est (minimum variance), **Linear** (linear function of the data), and **U**nbiased $\left(E[\hat{\beta}] = \beta\right)$**E**stimator of the coefficients in β. BEST adds up to a minimum MSE among linear estimators (Strang, 2005).

To maintain basic assumptions of multiple regression, the following statistical tests were performed:

a) Stationarity of the data series was checked using stationarity and unit root test for both crop yield and climate variables, i.e., Augmented Dickey Fuller test.
b) Heteroskedasticity was examined by using Breusch Pagan and Koenker test and visual inspection (Regression standardized predicted value, x axis vs Regression standardized residual, y axis).
c) Multicollinearity was checked by using tolerance and VIF (Variance Inflation Factor).
d) Autocorrelation was tested by using Durbin Watson Statistic.
e) Normality assumption of the regression residuals was examined by using Shapiro-Wilk test, Kolmogorov-Smirnov test and histogram.

2.4.2.1.1 Breusch-Pagan test

One of the key assumptions of regression is that the error variance should be constant (homoskedastic). If data are not homoskedastic, OLS estimates will not be BLUE (unbiased and efficient). This test is based on using the LM (Lagrange Multiplier) statistic is known as the Breusch-Pagan Test (Breusch and Pagan, 1979) for Heteroskedasticity. The statistic is,

$$\mathrm{LM} = \mathrm{n} \times \mathrm{R}^2_{\hat{\mathrm{e}}^2}$$

where $R^2_{\hat{e}^2}$ is R^2 of the artificial regression between original regression residuals vs predictors and n is the sample size. The null hypothesis is that H_0 = Homoskedasticity (no heteroskedasticity) and alternative hypothesis, H_a = Heteroskedasticity. If $p<0.05$, then reject H_0. The test was performed by using SPSS macro.

2.4.2.1.2 Tolerance and VIF

Predictors that are highly collinear, i.e. linearly related, can cause problems in estimating the regression coefficients and its standard error can get widely inflated. There are mainly two methods of detecting multicollinearity in a regression model:

(a) Tolerance: is an indication of the percent of variance in the predictor that cannot be accounted for by the other predictors**.**

(b) VIF: Variance Inflation Factor.

The formula to calculate Tolerance and VIF are as follows:

$$\mathrm{Tolerance} = 1 - \mathrm{R}_\mathrm{j}^2, \qquad \mathrm{VIF} = \frac{1}{\mathrm{Tolerance}}$$

where R_j^2 is the coefficient of determination of a regression of explanator *j* on all the other explanators**.** Multicollinearity problem arises if tolerance <0.20 and VIF> 5 (O'Brien, 2007). The test was automatically performed with multiple regression analysis in SPSS.

2.4.2.1.3 Durbin-Watson statistic

Autocorrelation is the phenomena that describes a relationship (correlation) between values separated from each other by a given time lag in a time series data. It is also known as serial correlation. The variance of random term u may be seriously underestimated if the u's are autocorrelated. The standard test to detect autocorrelation is the Durbin-Watson statistic (Durbin and Watson, 1971). It is denoted as d.

$$d = \frac{\sum_{t=2}^{T}(e_t - e_{t-1})^2}{\sum_{t=1}^{T} e_t^2}$$

where e_t is the residual associated with the observation at time t, where T is the number of observations. The value of d ranges from 0 to 4; A value close to 0 indicates strong positive autocorrelation, while a value of 4 indicates strong negative autocorrelation; value around 2 means no serial correlation. As most time series data exhibit positive autocorrelation, the null hypothesis, H_0: $\rho = 0$ (No serial correlation) and alternative hypothesis, H_a: $\rho > 0$ (Positive correlation). Upper and lower critical values, dU and dL have been tabulated in Durbin-Watson Table. If $d < dL$, reject H_0: $\rho = 0$; If $d > dU$, do not reject H_0 : $\rho = 0$ and If $dL < d < dU$, test is inconclusive. In SPSS, it is included as an option in the Regression function.

2.4.2.1.4 Shapiro-Wilk and Kolmogorov-Smirnov test:

The test was employed to test the normality assumption of the regression residuals. The test gives us a W statistic; the formula for the W statistic (Shapiro and Wilk, 1965) is:

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

where, x_i are the ordered random sample values and a_i are constants generated from the covariances, variances and means of the sample (size n) from a normally distributed sample (Shapiro-Wilk Table-1). The null hypothesis, H_0 is that data are normally distributed while alternative hypothesis, H_a is that data are not normally distributed. If p value <0.05, then reject H_0.

As the test is biased by sample size (Field, 2009); it can be statistically significant from a normal distribution in large sample size. As a result, a histogram plot is necessary in addition to the test. Another test named Kolmogorov-Smirnov is also used to test the normality of distribution, but the test is less powerful than Shapiro-Wilk (Daniel, 1990). Both tests were conducted in SPSS.

2.4.2.1.5 Stationarity and unit root test

The use of any regression model using the time series data requires the respective variables to be stationary which means that the mean and variance of each variable do not change systematically over time. As the time series data of the present study included data over 20 years, it is necessary to check stationarity before performing regression (Chen et al., 2004). Direct use of non-stationary data in the regression model can create spurious findings (Gujrati, 2004). A time series variable is referred to be non-stationary (or stationary) if it has non-constant (or constant) mean, variance and autocovariance (at various lags) over time. If a non-stationary time series needs to be differenced d times to become stationary, then it is referred to be integrated of order d, i.e. I(d) (Sarker, 2012). The most common and very popular method of determining the stationarity of a time series is the Augmented Dickey-Euller (ADF) test. Therefore, ADF test (Dickey and Fuller, 1979) was executed for all the time series to examine the presence of unit roots. The augmented Dickey–Fuller test fits a model of the form:

$$\Delta y_t = \alpha + \beta y_{t-1} + \delta t + \varsigma_1 \Delta y_{t-1} + \varsigma_2 \Delta y_{t-2} + \cdots + \varsigma_k \Delta y_{t-k} + \epsilon_t$$

Where $\Delta y_t = y_t - y_{t-1}$ and so on, α= intercept/constant, t= time or trend variable, k= the number of lags, ε = pure white noise term. The specification of the lag length p is also important to use ADF test. A common rule of thumb for determining p_{max}, suggested by Schwert (1989), is

$p_{max} = \left[12\ .\left(\frac{T}{100}\right)^{1/4}\right]$ where T is the number of observations.

The test for a unit root has the null hypothesis that β = 0. If the coefficient is statistically different from 0, the hypothesis that Y_t contains a unit root is rejected. The test was performed by using Stata 13.

2.4.2.1.5.1 Augmented Dickey-Fuller test

The results of the Augmented Dickey-Fuller test are presented in Table 2.3. In case of dependent variables (crop yield), it was found that yield of Aman rice and Pulse showed integration of order I(0) indicating non-stationarity of this two data sets. On the other hand, yield of Aus rice, Boro rice and Groundnut exhibited integration of order I(1) demonstrating the presence of a unit root in the level data for these three variables.

Table 2.3: Augmented Dickey-Fuller test for checking the stationarity of data series

<table>
<tr><th>Model Variables</th><th colspan="5">Integration of Order</th></tr>
<tr><td rowspan="2">Crop Yield</td><td>Aus</td><td>Aman</td><td>Boro</td><td>Pulse</td><td>Groundnut</td></tr>
<tr><td>I(1)</td><td>I(0)</td><td>I(1)</td><td>I(0)</td><td>I(1)</td></tr>
<tr><td rowspan="2">Climate Variables</td><td colspan="5">Growing Season</td></tr>
<tr><td colspan="2">Kharif-1</td><td colspan="2">Kharif-2</td><td>Rabi</td></tr>
<tr><td>Maximum Temperature</td><td colspan="2">I(0)</td><td colspan="2">I(0)</td><td>I(0)</td></tr>
<tr><td>Minimum Temperature</td><td colspan="2">I(0)</td><td colspan="2">I(0)</td><td>I(0)</td></tr>
<tr><td>Rainfall</td><td colspan="2">I(0)</td><td colspan="2">I(0)</td><td>I(0)</td></tr>
<tr><td>Relative Humidity</td><td colspan="2">I(0)</td><td colspan="2">I(0)</td><td>I(0)</td></tr>
<tr><td>Sunshine Duration</td><td colspan="2">I(0)</td><td colspan="2">I(0)</td><td>I(0)</td></tr>
</table>

However, in view of independent variables, it was discovered that five major climate variables for all three growing seasons displayed integration of order I(0); therefore, these variables were stationary in their level form. The variables with I(1) were first differenced before computation (McCarl et al., 2008). As most of the variables are not integrated at the same order under each model, a Johansen co-integration test was not executed; instead a multiple regression analysis using OLS method with the differenced variables was conducted (Gujrati, 2004). For the same ground, causality test was also not performed. Because it is hypothesized that yield changes are caused by climate variations and not vice versa (Lobell and Field, 2007).

2.4.2.3 Non-climatic trend removal of crop yield

Notable positive trend exists between crop yields and time. Rise in crop yield is mostly contributed to the technological improvement, so the contributions of climate change are difficult to determine from the raw yield data. Therefore, it is necessary to remove the yield trend caused by non-climate factors (improved variety, technological improvement, fertilizers, pesticides, etc.). Generally, five type of statistical techniques are used in literature to remove its trend: (i) Crop yields are considered as a function of time, and yields are divided into two parts including trends and variations. The trend yields depict the yields of historical productivity while the variation yields depict the yields affected by climate. This linear regression method also encounters higher absolute values of variation, known as heteroskedasticity, which violate some of the basic assumptions of linear regression. (ii) If crop yield trend changed by time is prominent with non-linear trend, higher order polynomials can be an option. (iii) Adding time variables like year and year-squared in regression model is also a method considering technological advances. (iv) In order to control heteroskedasticity in linear regression, log-transformation can transform absolute differences to relative differences. (v) Another technique commonly used is first-differences to analyze time-series, that is, crop yield in this year subtracts the yield in the previous year. At the same time, climate data are also dealt with like this. This method can focus on year to year variation, so it can reduce the long-term trend of technical advances. (Lobel and Field, 2007; Wenjiao et al., 2013; Amin et al., 2015). The fourth and the fifth method were used separately or combined for the present study. Consequently, the following format of regression modeling was used for the selected five major food crops:

$$\mathbf{Y_{it} = \alpha + \beta_1 MaxT_{it} + \beta_2 MinT_{it} + \beta_3 Rain_{it} + \beta_4 RHumid_{it} + \beta_5 Sunshine_{it} + \epsilon_{it}}$$

Where,

Y = Yield in kg/acre

i = 1, 2, …….. , 5; 1 means Boro rice, 2 means Aman rice, 3 means Aus rice, 4 means Pulse and 5 means Groundnut;

α = Constant term

MaxT= Growing season average daily maximum temperature (°C)

MinT = Growing season average daily minimum temperature (°C)

Rain = Growing season total daily rainfall (mm)

RHumid = Growing season average daily relative humidity (%)

Sunshine= Growing season average daily sunshine duration (hours)

ϵ= Error term

t = Time (year)

2.4.2.4 Prior assumption of crop yield-climate relationship

In case of each crop yield model, a preliminary assumption is that the crops that we grow for food require certain environmental conditions to live, such as the optimum temperature, soil moisture, relative humidity and sunshine. A change in major climate variables may have both positive and negative impacts on crop yields. Maximum and minimum temperature influences crop growth by boosting photosynthesis thereby enhancing crop production as it rises (Sombroek and Gommes, n.d.). But very high temperature affects various metabolic processes of plants heterogeneously including the stability of various proteins and membranes and the effectiveness of enzymatic reactions in the cell via denaturation, resulting in metabolic imbalance. High-temperature stress also causes a decrease in photosynthesis rate by affecting photosystem II and Rubisco activity and thus affecting crop yield (Mathur and Jajoo, 2015). On the contrary, very low temperature can induce chilling injury in plants which results in irreversible changes in the metabolic processes and aberrations and ultimately reduces crop yield (Bhandari and Nayyar, n.d.). Rainfall increase affects crop production positively by readily dissolving the nutrients for easy soil absorption by plants (IPCC, 2001). However, excessive rainfall especially during the monsoon season can increase soil erosion and the loss of plant nutrients in soil due to surface runoff. It can also causes severe floods which eventually disrupt crop production and leave farmers with no food to subsist and sell. As a result, farmers can suffer production losses due to insufficient and erratic rainfall during the rainy season (Lichtenstein, n.d.). As humidity directly affects temperature, very high or very low relative humidity is not favorable for higher grain yield. Low relative humidity can dry up products and high relative humidity can increase the water activity and growing mould and bacteria in the production. Crops inclined to absorb soil nutrients for optimum yield when there is sufficient humid air. Relative humidity directly influences the water relations of plant and indirectly affects leaf growth, photosynthesis, pollination, occurrence of diseases and finally crop yield. In addition, atmospheric dryness can reduce dry matter production through stomatal control and leaf water potential (TNAU Agritech Portal, 2016). Sunshine (light) directly affects crop growth and flowering by increasing photosynthesis and feeding plants energy. Plants are dependent on solar radiation to produce food, complete their life cycle and ease healthy growth and development. On the other hand, excessive sunshine shows similar negative impacts on crop yield like higher temperature stress (Smestad, n.d.). Therefore, changes or deviations in major climate variables would be likely to have several significant impacts on crop yields.

2.5 Cropping pattern change and causes

2.5.1 Cropping pattern change

Cropping pattern and its changes were determined in two methods; one method was using simple statistical analysis of time series data and another method was using farmers' survey data. Graphical tools such as Pie and Bar Chart were used for its visual interpretation.

2.5.2 Causes of cropping pattern change

Causes of cropping pattern change were also investigated in two dimensions. The first strategy was to get farmers' opinion obtained from questionnaire survey data. The second approach was to verify the farmers' view regarding cropping pattern change by making relevant discussions (analyzing some relevant data and literature related to cropping pattern change).

2.6 Farmers' adaptation options and its determinants

2.6.1 Farmers' perception on climate change

Farmers' perceptions on potential climate change were investigated by analyzing questionnaire survey data with some graphical tools.

2.6.2 Adaptation options, adjustment and barriers to adaptation

Farmers' adaptation to climate change, adjustment options in adopting adaptation and barriers to adaptation were explored by using farmers' survey data and FGDs. Standard graphical tools such as Pie and Bar Chart were also used for its interpretation.

2.6.3 Determinants of farmers' choice of adaptation methods

2.6.3.1 Analytical framework

In order to capture the determinants that affect farmers' adaptation to climate change, a model based on the theory of random utility is employed. The decision on whether or not to accept an adaptation method is evaluated under the common framework of utility or profit maximization (Pryanishnikov and Katarina, 2003). As there is no natural ordering in the preferred choices and a monotonic association between a latent or unobservable variable and the observed outcome is not practical, a random utility framework model is rationalized (Verbeek, 2004). It is expected that farmers utilize adaptation methods only when the perceived utility or net benefit from using such a method is notably higher than is the case without it. According to the theory, the utility of each choice is modelled as a linear function of observed attributes plus an additive error term.

More distinctly, the utility a farmer i from alternatives j and k is expressed by

$$U_{ij} = V_{ij} + \varepsilon_{ij} \ldots\ldots\ldots\ldots\ldots\ldots. (2.9)$$

$$U_{ik} = V_{ik} + \varepsilon_{ik} \ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

respectively; where V_{ij} and V_{ik} denote the deterministic or systematic part of the utility, and ε_{ij} and ε_{ik} demonstrate the stochastic part which means the uncertainty. According to utility or profit maximization, if a farmer i decides to adopt option j, it follows that the perceived utility or benefit from option j is greater than the utility from other options (say k) depicted as: $U_{ij} > U_{ik}$ for all $k \neq j$.

Assuming V( ) is a linear function of x_i, observed factors to the farmer's utility, a general formulation of equations (2.9) and (2.10) is given by:

$$U_{ij} = x_i\beta_j + \varepsilon_{ij}$$

$$U_{ik} = x_i\beta_k + \varepsilon_{ik}$$

Afterward, by denoting $Y_i = j$ and the farmer's choice of alternative j, it can be written as,

$$P[Y_i = j/x] = P[U_{ij} > U_{ik}]$$

$$= P[x_i\beta_j + \varepsilon_{ij} - x_i\beta_k - \varepsilon_{ik} > 0|x]$$

$$= P[x_i(\beta_j - \beta_k) + \varepsilon_{ij} - \varepsilon_{ik} > 0 \mid x]$$

$$= P[x_i\beta + \varepsilon > 0 \mid x]$$

where β is a vector of unknown coefficients which can be described as the net effects of a vector of explanatory variables affecting choice of adaptation and ε is a random error term. The error term, ε for all alternatives is assumed to be independent and identically distributed (i.i.d) conditional on x_i, with the type I extreme value distribution. Then, the probability that a farmer will select alternative j is shown by

$$P(y = j/x) = \frac{\exp(x\beta_j)}{[1 + \sum_{h=1}^{J} \exp(x\beta_h), \ j=1,\ldots,J]}$$

This is called the MNL model (Greene, 2003; Sarker, 2012).

2.6.3.2 Empirical model

The multinomial logit (MNL) model is employed to determine the significant determinants of farmers' adaptation choices in the present study. This method has been extensively used to investigate crop (Hassan and Nhemachena, 2008; Kurukulasuriya and Mendelsohn, 2008) and livestock (Seo and Mendelsohn, 2008) choices as methods to adapt to the negative impacts of climate change. The main advantage of the MNL is that it permits examining the decisions of adaptation choices across more than two categories, enabling the estimation of choice probabilities for different categories (Wooldridge, 2002).

In order to explain the MNL model, let assume that *y* represents a random variable having the values {1, 2...*J*} for *J* , a positive integer, and ***x*** represents a set of control or explanatory variables. In this case, *y* demonstrates different adaptation choices or categories and ***x*** incorporates different household, socio-economic, institutional and environmental factors. The argument or question is how cetirus paribus changes in the elements of ***x*** influence the response probabilities *P*(*y* = *j* / *x*), *j* =1, 2, ..., *J.* As the probabilities should sum to unity, *P*(*y* = *j* / *x*) is estimated once we know the probabilities for *j* = 2, ..., *J.* Let ***x*** be a 1× *K* vector with first element unity. The MNL model has response probabilities:

$$\mathrm{P}(\mathrm{y} = j/x) = \frac{\exp(x\beta_j)}{[1+\sum_{h=1}^{J}\exp(x\beta_h),\ \ j=1,....,J]} \quad \text{........................ (2.11)}$$

where B_j is K×1; j =1, . . . , J.

Nonetheless, the parameter estimates of the MNL model only exhibit the direction of the effect of the explanatory variables on the dependent variable. The actual magnitude of changes or probabilities is not incorporated by the estimates. Moreover, parameter estimates are difficult to explain as they are obtained from non-linear estimates (Greene, 2003). As a result, the MNL model parameters are converted into relative risk ratios (RRR) by exponentiating the coefficients, $e^{coef.}$. Noted that the RRR estimates the effects on the relative odds of one outcome being chosen relative to the base outcome for a unit change in any of the explanatory variables.

2.6.3.3 Basic assumptions of MNL model

In order to obtain unbiased and consistent parameter estimates of the MNL model in Eq. (2.11), the basic assumption of independence of irrelevant alternatives (IIA) is required to meet in the model. More precisely, the IIA assumption necessitates that the probability of adopting a certain adaptation method by a particular household needs to be independent from the probability of choosing another adaptation method (that is, P_j /P_k is independent of the remaining probabilities). The proposition of the IIA assumption is the independent and homoscedastic disturbance terms of the fundamental model in Eq. (2.11). Three statistical tests such as Hausman, Suest based Hausman and Small-Hsiao test were conducted to know whether or not IIA assumption was met in the model. Statistical software package "Stata 13" was used to run the model including the above mentioned tests.

2.6.3.4 Model variables

Different adaptation methods practiced by farmers in the study area were used as dependent variables and different factors or determinants that affect farmers' adaptation choices were used as independent variables in the MNL model.

Chapter Three: Results

3.1 Annual and seasonal climate variation

3.1.1 Annual climate variability

3.1.1.1 Descriptive statistics

The descriptive statistics of five major annual climate variables were estimated to get a general idea about the properties of variables for the entire study period (Table 3.1). The most important descriptive statistics that were calculated include mean, standard deviation, coefficient of variation, skewness, kurtosis, minimum and maximum. The mean value of maximum temperature, minimum temperature, total rainfall, relative humidity and sunshine duration in Greater Noakhali region over the study period found to be 30.33 ^{0}C, 21.68 ^{0}C, 3011.12 mm, 80.89% and 6.29 hours respectively. The highest value of CV (14.99%) was observed in rainfall in the study area, indicating the highest rainfall variability in compared to other climate variables. Moreover, sunshine duration also demonstrated a considerable variability (5.89%), the second highest in the region.

Table 3.1: Descriptive statistics of climate variables over the 1985-2014 period

Statistics	Climatic Variables				
	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Rainfall (mm/year)	Relative Humidity (%)	Sunshine Duration (hours/day)
Mean	30.33	21.68	3011.12	80.89	6.29
S.D.	0.33	0.29	451.33	0.77	0.37
CV(%)	1.08	1.34	14.99	0.95	5.89
Kurtosis	-0.21	-0.27	0.35	-0.89	-0.90
Skewness	-0.05	0.22	0.08	-0.31	-0.12
Minimum	29.71	21.16	1892.00	79.46	5.65
Maximum	30.95	22.35	3868.00	82.29	6.98

Source: Authors' own estimation based on BMD (2015).

The descriptive statistics of major climate variables were also estimated for the preceding three decades to ascertain the climate variability over the periods (Table 3.2). However, in this occasion, only mean, standard deviation and CV were computed as they provide an in-depth perception about climate variability and change. In particular, standard deviation and CV are respective indices of absolute variability and relative variability. It was disclosed that mean maximum and minimum temperature were increased steadily (30.07 to 30.59 ^{0}C and 21.44 to 21.85 ^{0}C correspondingly) although their variability showed no significant pattern over the decades. At the same time, it was observed that both rainfall and its variability were decreased greatly (3118 to 2874 mm and 21.31 to 11.34% respectively). In addition, no significant pattern in variability was noted for relative humidity and sunshine duration.

Table 3.2: Climate variability of Greater Noakhali Region in last three decades.

Major climate variable	**Statistical tool**	**1985-1994**	**1995-2004**	**2005-2014**
Mean annual maximum temperature (^{0}C)	Mean	30.07	30.34	30.59
	Standard deviation	0.27	0.20	0.28
	CV (%)	0.91	0.64	0.93
Mean annual minimum temperature (^{0}C)	Mean	21.44	21.74	21.85
	Standard deviation	0.22	0.22	0.28
	CV (%)	1.04	0.99	1.26
Annual total rainfall (mm)	Mean	3118.15	3041.45	2873.75
	Standard deviation	664.40	272.00	325.95
	CV (%)	21.31	8.94	11.34
Mean annual relative humidity (%)	Mean	80.70	80.83	81.15
	Standard deviation	0.88	0.69	0.74
	CV (%)	1.09	0.86	0.91
Mean annual sunshine duration (hours/day)	Mean	6.29	6.59	6.00
	Standard deviation	0.34	0.25	0.27
	CV (%)	5.35	3.78	4.49

Source: Authors' own calculation based on BMD (2015).

3.1.1.2 Moving average

Five yearly moving average of annual climate variables was measured to smooth out short term fluctuations and highlight long term trends. Consequently, the time period decreased from 1985-2014 to 1987-2012. Coefficient of variation (CV) was also measured on the corresponding five-yearly figures.

The variability in mean annual maximum temperature can be detected visually over the periods from the Figure 3.1. Overall, mean annual maximum temperature seemed to decrease up to 1991, then inclined to increase markedly up to 2012 with some fluctuations over the period. Though the overall trend was rising.

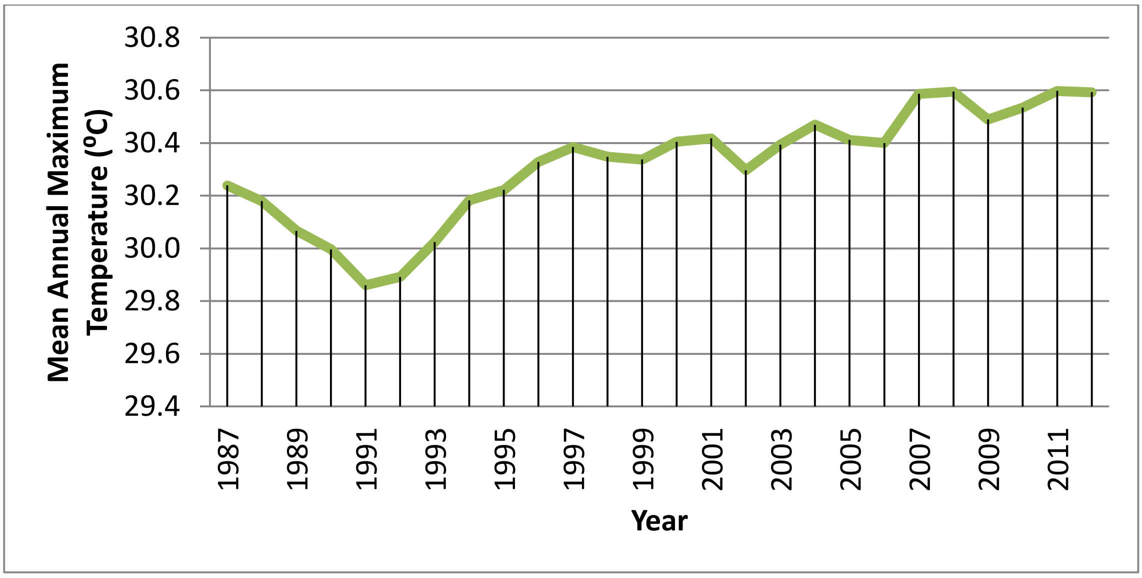


Figure 3.1: Moving average of mean annual maximum temperature.

Coefficient of Variation (CV) is a usual index of measuring relative variability. The relative variability of mean annual maximum temperature is shown in Figure 3.2. It showed sharp fluctuations up to 2001 with certain interval, then it increased quickly up to 2005 and finally moved into a downward trend. However, the relative variability over the period increased to a higher mean value.

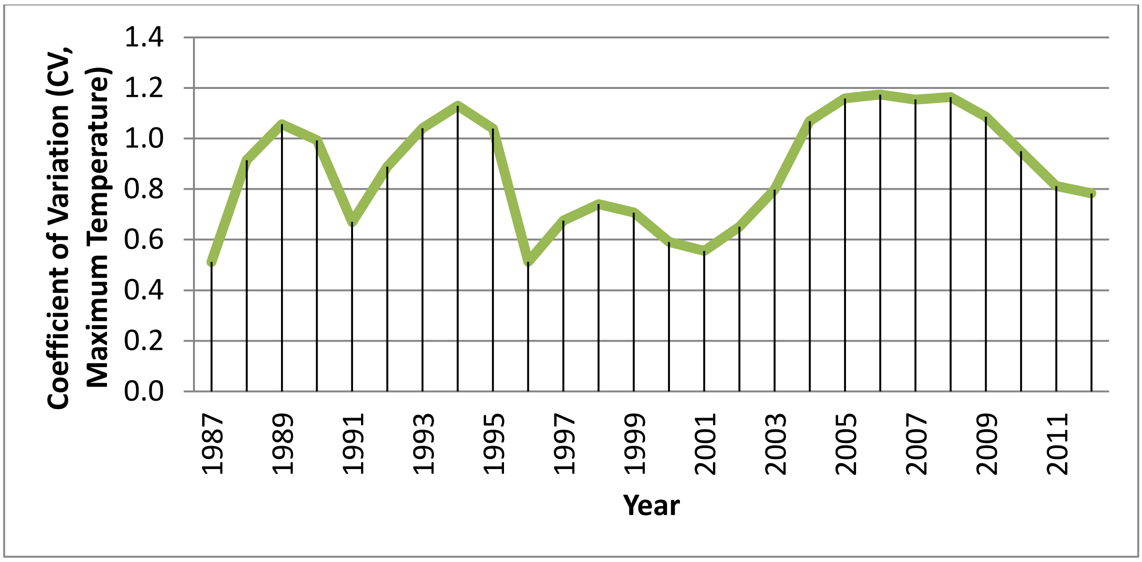


Figure 3.2: Coefficient of variation in mean annual maximum temperature.

The variability of mean annual minimum temperature against time is depicted in Figure 3.3. The variable exhibited a steady upward trend over the period with some ups and downs confirming the variability of the concerned climate variable.

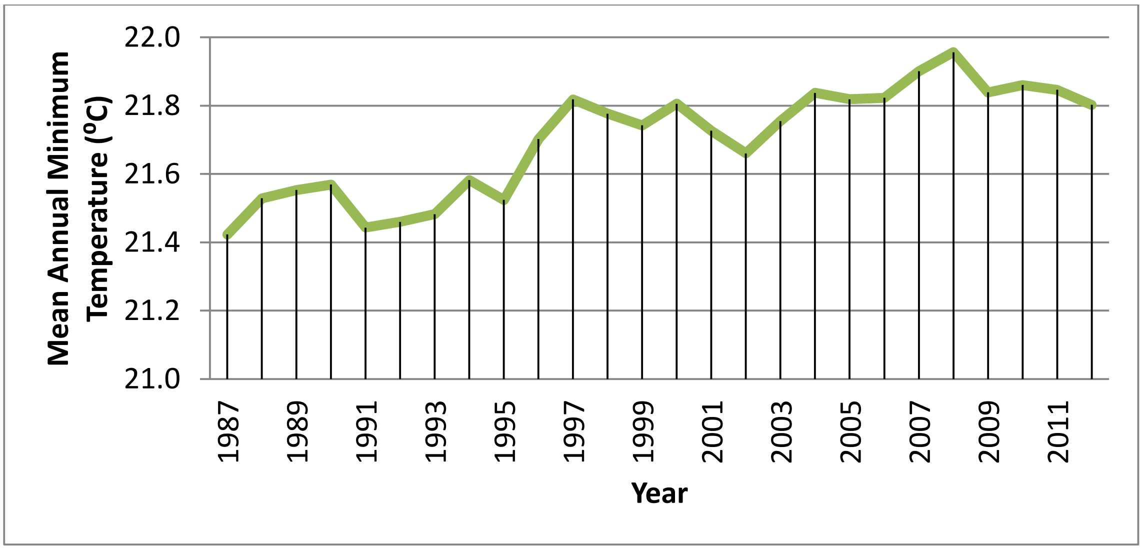


Figure 3.3: Moving average of mean annual minimum temperature.

The behavioral pattern of relative variability in mean annual minimum temperature over the study period is examined in Figure 3.4. The relative variability increased slightly with some steady fluctuations up to 1999 and then, decreased very rapidly up to 2002. Afterwards, it showed a sharp upward trend until 2009. The variability in mean annual minimum temperature was identified by the aforesaid patterns.

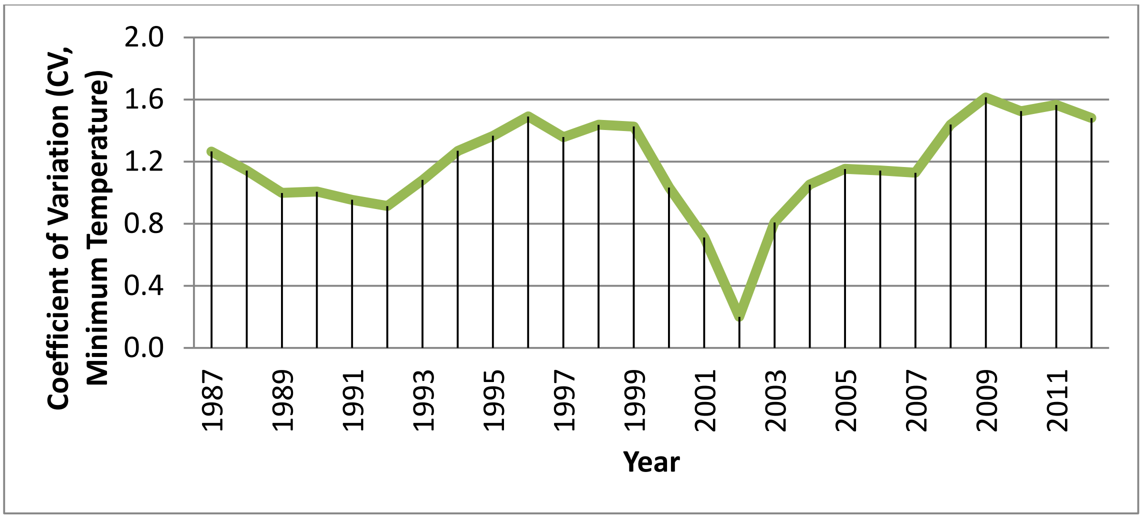


Figure 3.4: Coefficient of variation in mean annual minimum temperature.

The mean annual rainfall is graphed against time (Figure 3.5). Mean annual rainfall demonstrated a stable decreasing trend with some shifting over the period documenting the variability of the mean annual rainfall in the region.

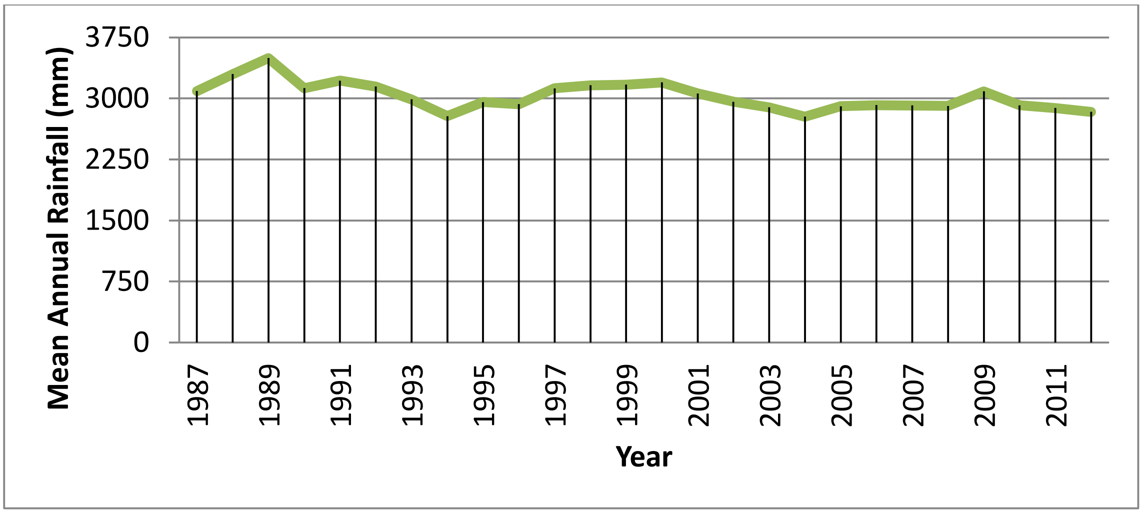


Figure 3.5: Moving average of mean annual rainfall

The relative variability of mean annual rainfall is illustrated in Figure 3.6. It exhibited a sudden rising trend until 1992, then decreased gradually up to 2003, then again increased. Although the relative variability, on average, decreased to a lower value over the time period.

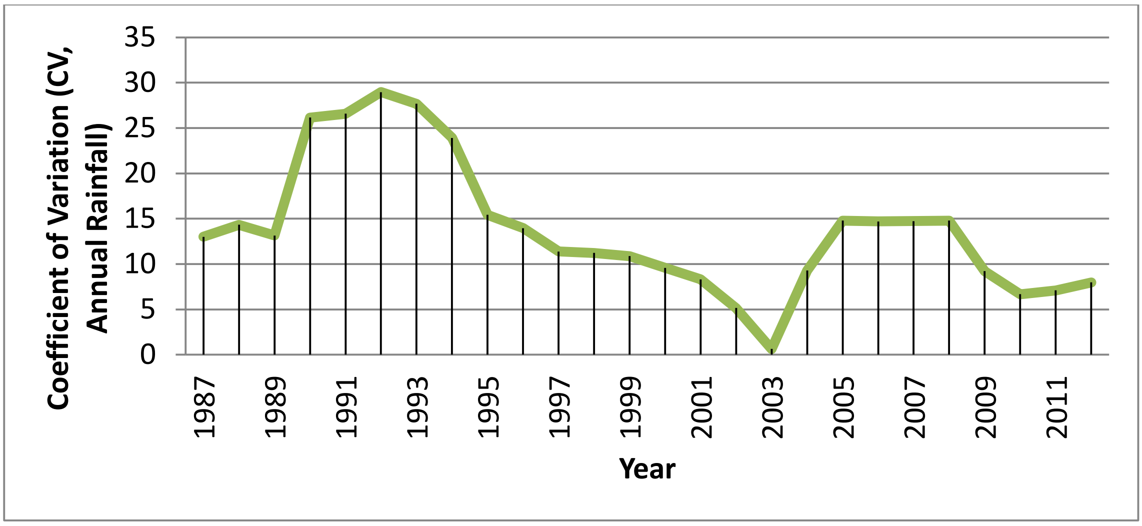


Figure 3.6: Coefficient of variation in annual rainfall.

A gradual fluctuations in the variability of mean annual relative humidity is noticed in Figure 3.7. Although it demonstrated an increasing trend of the variable over the period.

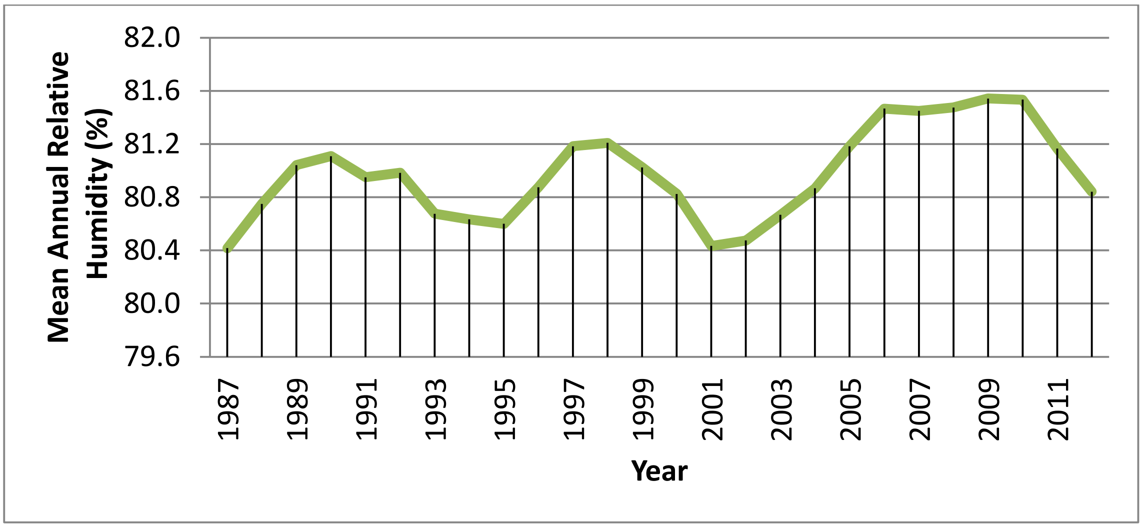


Figure 3.7: Moving average of mean annual relative humidity.

The relative variability of mean annual relative humidity displayed a steady decrease up to 2010 with some variations and then it exhibited a very rapid upward trend (Figure 3.8).

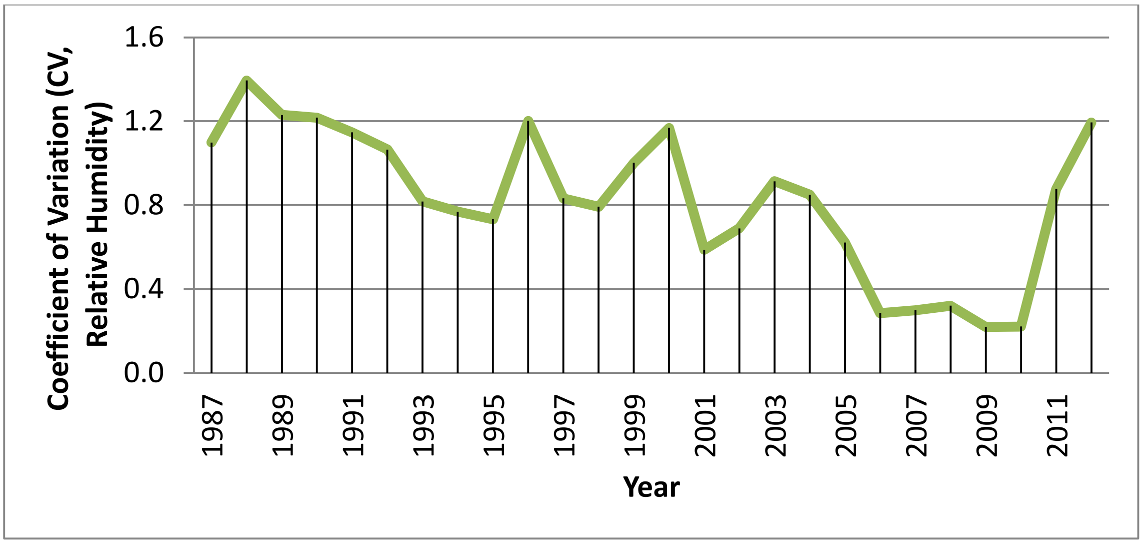


Figure 3.8: Coefficient of variation in mean annual relative humidity.

Mean annual sunshine duration expressed an overall downward trend over the period. Nevertheless, it showed a steady upward trend in the middle of the time period (Figure 3.9).

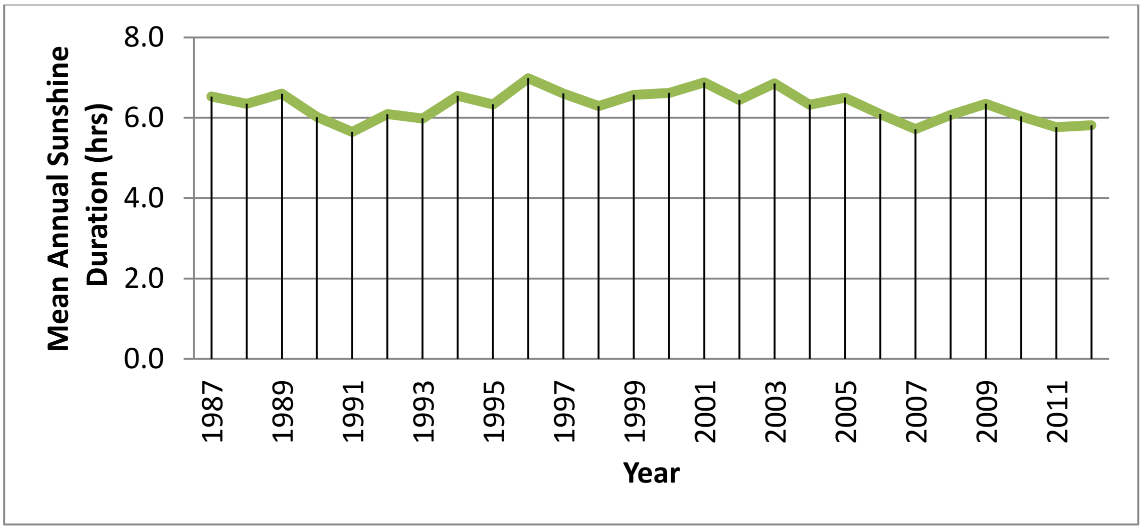


Figure 3.9: Moving average of mean annual sunshine duration.

The relative variability of mean annual sunshine duration was also investigated using moving average method (Figure 3.10). It exhibited a rising trend until 1989, then it decreased steadily with some ups and downs up to 2001, then it started to increase again until 2011 with some sharp fluctuations.

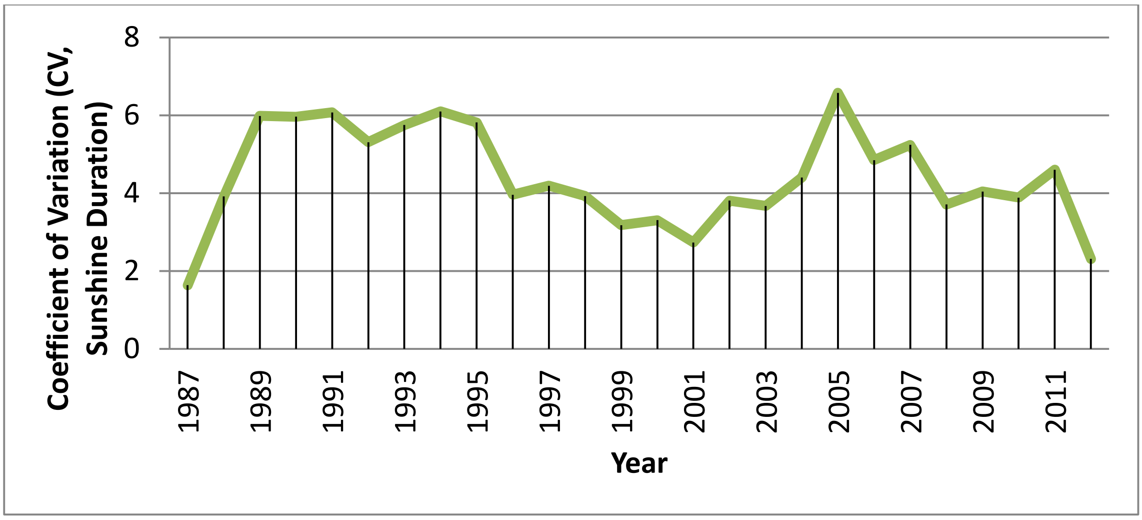


Figure 3.10: Coefficient of variation in mean annual sunshine duration.

3.1.1.3 Linear trend model

Besides above descriptive statistics, linear trend model was employed to determine the exact trend in annual climate variables with time (year) as an independent variable. The results of the linear trend model are shown in Table 3.3. Moreover, scatter plots (time trends) of annual climate variables with regression equation are also presented in Figure 3.11 to 3.16. The model revealed that mean temperature, maximum temperature, minimum temperature and sunshine duration displayed significant trend ($p<0.05$) whereas rainfall and relative humidity showed no significant trend over the periods ($p>0.05$). Among the significant climate variables, positive trend was noticed in mean temperature, maximum temperature and minimum temperature while a negative trend was detected in sunshine duration.

Table 3.3: The results of the linear trend model of annual climate variables, 1985-2014.

Climate Variables	Coefficient for time (trend)	P value	R Square	Sig.
Mean Temperature (^{0}C)	0.0194	0.0004	0.362	***
Maximum Temperature (^{0}C)	0.0219	0.0007	0.3435	***
Minimum Temperature (^{0}C)	0.0169	0.0039	0.2604	***
Annual Rainfall (mm)	-12.7611	0.1847	0.062	NS
Relative Humidity (%)	0.0131	0.4308	0.0223	NS
Sunshine Duration (hrs)	-0.0172	0.0254	0.1661	**

*** and **,Significant at 1% and 5% probability level, respectively; NS: Not significant

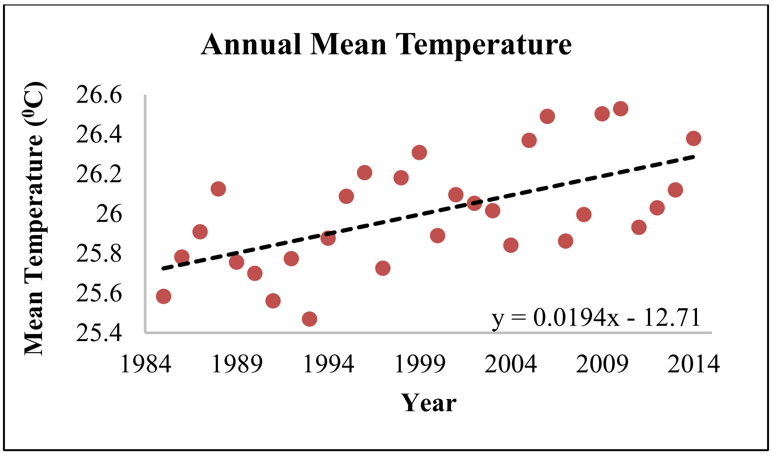


Figure 3.11: Trend of annual mean temperature, 1985-2014.

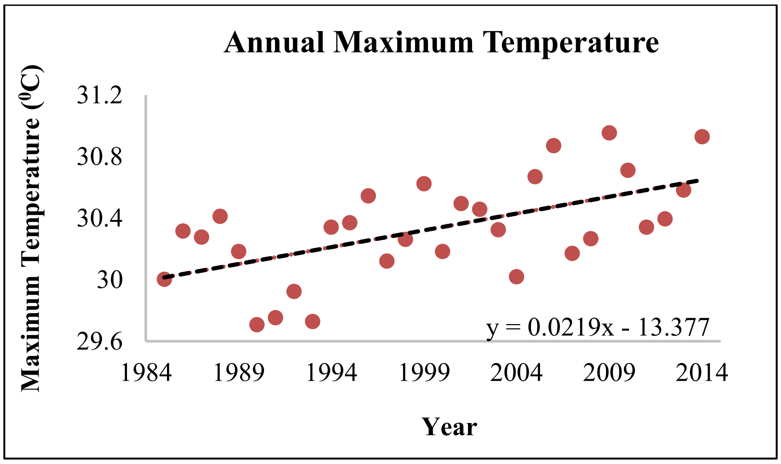


Figure 3.12: Trend of mean annual maximum temperature, 1985-2014.

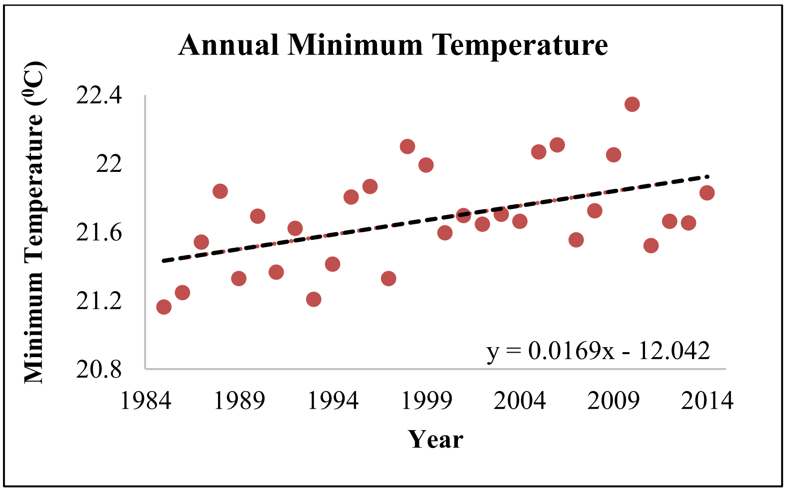


Figure 3.13: Trend of mean annual minimum temperature, 1985-2014.

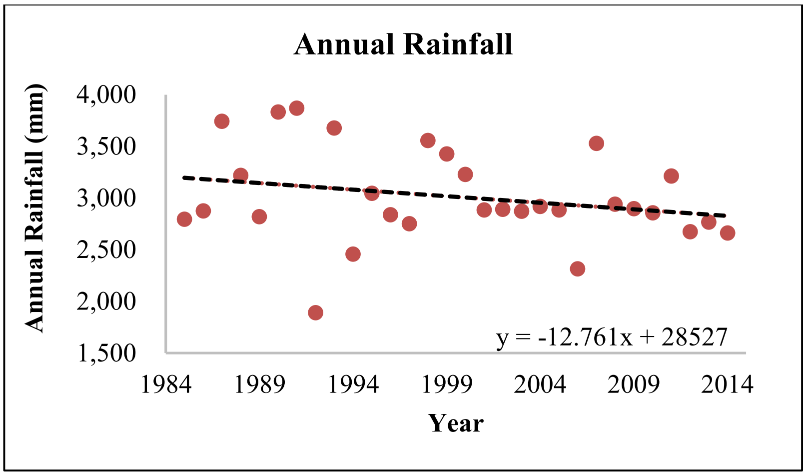


Figure 3.14: Trend of annual rainfall, 1985-2014

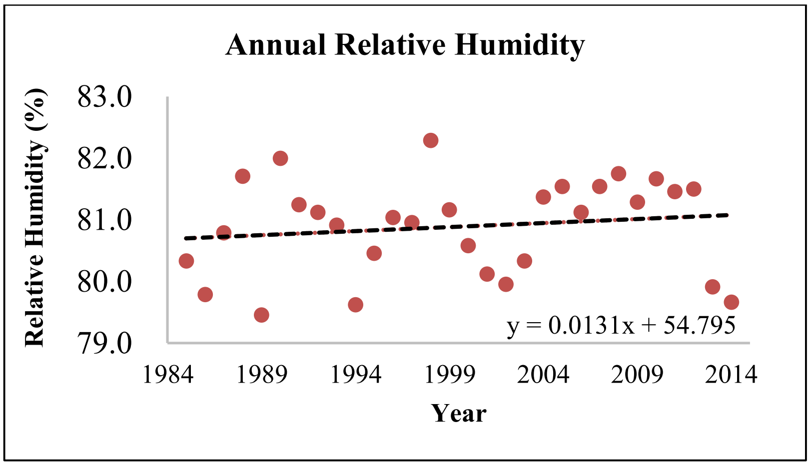


Figure 3.15: Trend of mean annual relative humidity, 1985-2014

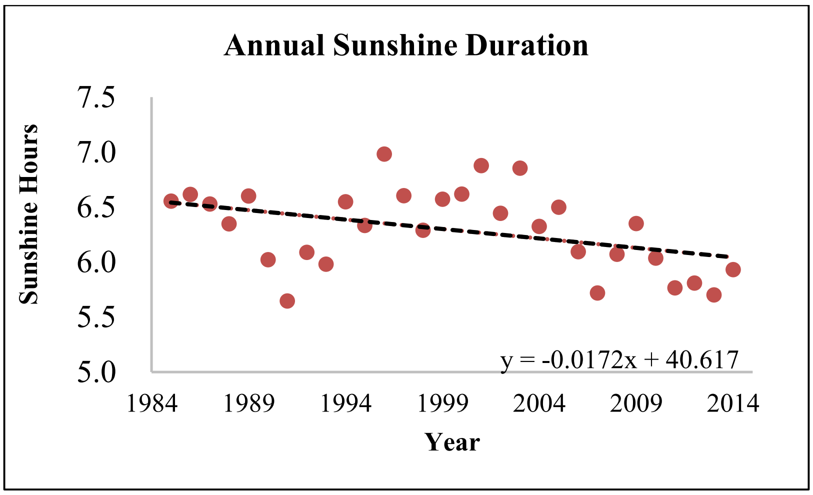


Figure 3.16: Trend of mean annual sunshine duration, 1985-2014

3.1.2 Growing season climate variability

3.1.2.1 Descriptive statistics

The descriptive statistics were estimated for growing season climate to get a primary idea about growing season climate variability and change (Table 3.4). In case of growing season climate variables, the highest maximum temperature was observed in Kharif-1

Table 3.4: Descriptive statistics of growing season climate, 1985-2014.

Growing Season Climate		Statistical Tools						
		Mean	S.D.	C.V. (%)	Kurtosis	Skewness	Min.	Max.
Kharif-1	Max. Temp. (^{0}C)	32.02	0.62	1.94	1.59	0.18	30.75	33.8
	Min. Temp. (^{0}C)	24.3	0.45	1.86	0.14	0.13	23.44	25.43
	Rainfall (mm/year)	1445.55	229.13	15.85	1.71	-0.54	770.5	1933
	R. Humidity (%)	81.95	1.35	1.64	-0.41	-0.46	79.01	84.59
	Sunshine (hrs/day)	5.84	0.41	7.03	-0.92	0.05	5.02	6.64
Kharif-2	Max. Temp. (^{0}C)	31.41	0.44	1.42	-0.67	-0.37	30.43	32.16
	Min. Temp. (^{0}C)	25.43	0.31	1.23	-0.74	-0.19	24.8	25.99
	Rainfall (mm/year)	1405.57	282.95	20.13	-0.2	0.42	949.5	2044
	R. Humidity (%)	85.95	0.85	0.99	-0.41	0.15	84.26	87.74
	Sunshine (hrs/day)	5.02	0.54	10.77	0.41	-0.29	3.61	6.05
Rabi	Max. Temp. (^{0}C)	28.7	0.5	1.73	0.96	-0.38	27.58	29.94
	Min. Temp. (^{0}C)	17.94	0.53	2.98	-0.49	0.19	16.99	19.06
	Rainfall (mm/year)	164.58	87.11	52.93	-0.85	0.33	29	348
	R. Humidity (%)	78.14	1.44	1.84	-0.9	-0.1	75.5	80.67
	Sunshine (hrs/day)	7.42	0.59	8.02	-0.09	-0.47	6.05	8.43

Source: Authors' own estimation based on BMD (2015).

season (33.8 ^{0}C) while the lowest maximum temperature was noticed in Rabi season (27.58 ^{0}C). In contrast, the highest minimum temperature was observed in Kharif-2 season (25.99 ^{0}C) while the lowest minimum temperature was also noted in Rabi season (16.99 ^{0}C). In addition, the highest rainfall was observed in Kharif-2 season (2044 mm) and the lowest rainfall was monitored in Rabi season (29 mm). In view of relative humidity, the highest percentage of humidity was experienced in Kharif-2 season (87.74%) while the lowest percentage of humidity was observed in Rabi season (75.5%). Lastly, the highest sunshine duration was observed in Rabi season (8.43 hrs) whereas the lowest sunshine duration was detected in Kharif-2 season (3.61 hrs).

3.1.2.2. Trend graph

In addition to descriptive statistics, trend graphs were constructed with time (year) as an independent variable to get a comprehensive impression about growing season difference in trend and variations of five major climate variables over the study period (Figure 3.17 to 3.21).

Though maximum temperature varies considerably, the overall trend was noticed to increase for all growing seasons except Rabi. In addition, the trend line of Kharif-1 season appeared to be in upper position all over the period.

In case of minimum temperature, an upward trend was detected with some ups and downs for all growing seasons excluding Rabi. But in this case, trend line of Kharif-2 season seemed to be in higher position all over the study period.

In view of rainfall, it was observed to demonstrate a downward trend with extreme fluctuations especially in Kharif-1 and Kharif-2 season influencing the crop yield substantially.

With variations all over the period, relative humidity displayed the upper-most trend line in Kharif-2 season.

Surprisingly, sunshine exhibited a downward trend for all growing seasons with distinct fluctuations all over the period.

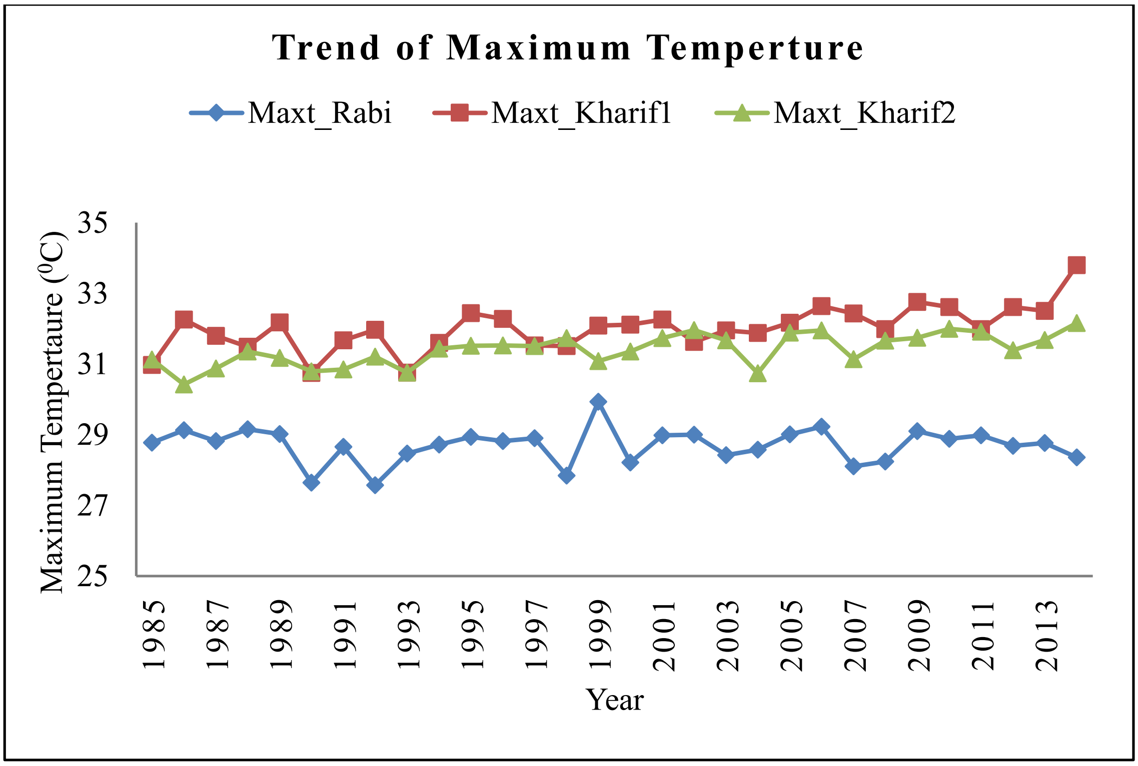


Figure 3.17: Trend and variation of mean maximum temperature in three growing seasons.

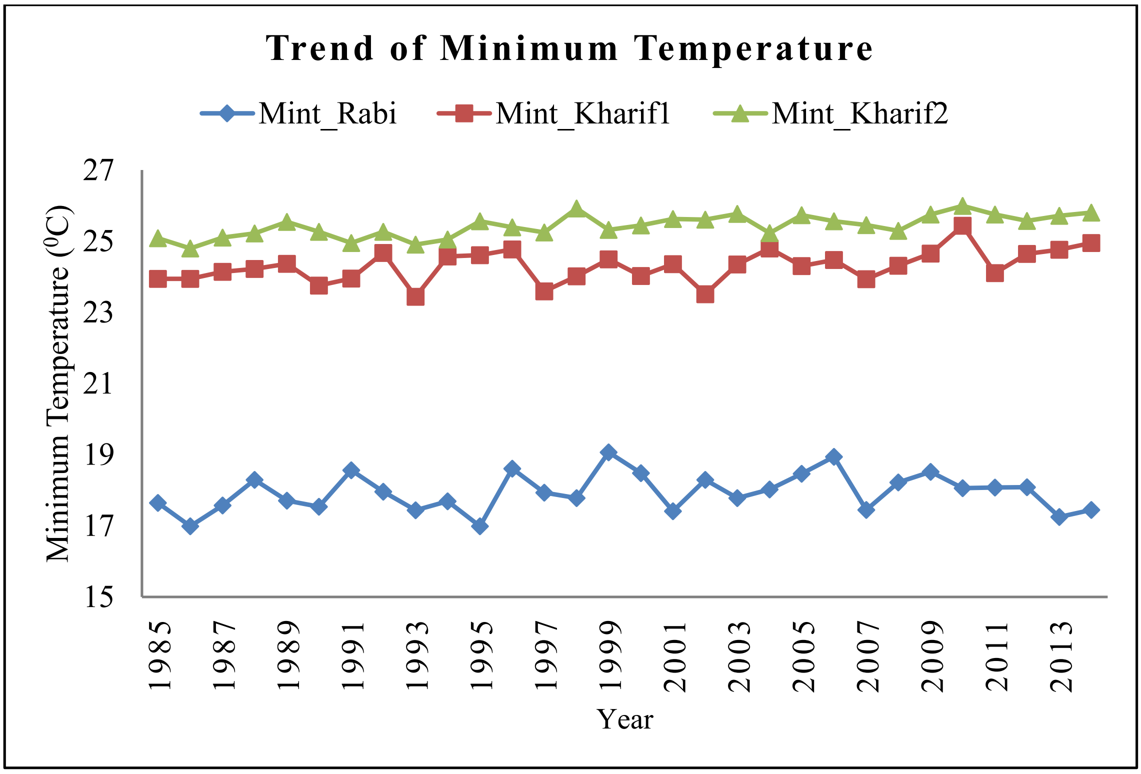


Figure 3.18: Trend and variation of mean minimum temperature in three growing seasons.

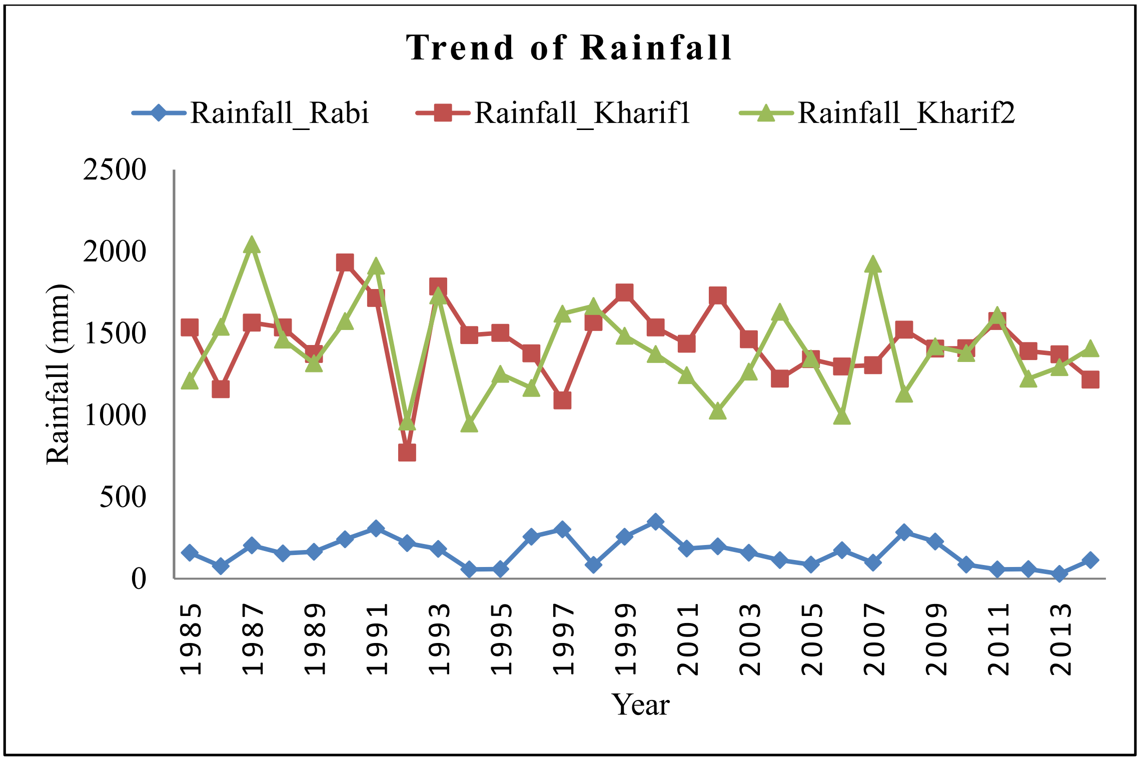


Figure 3.19: Trend and variation of total rainfall in three growing seasons.

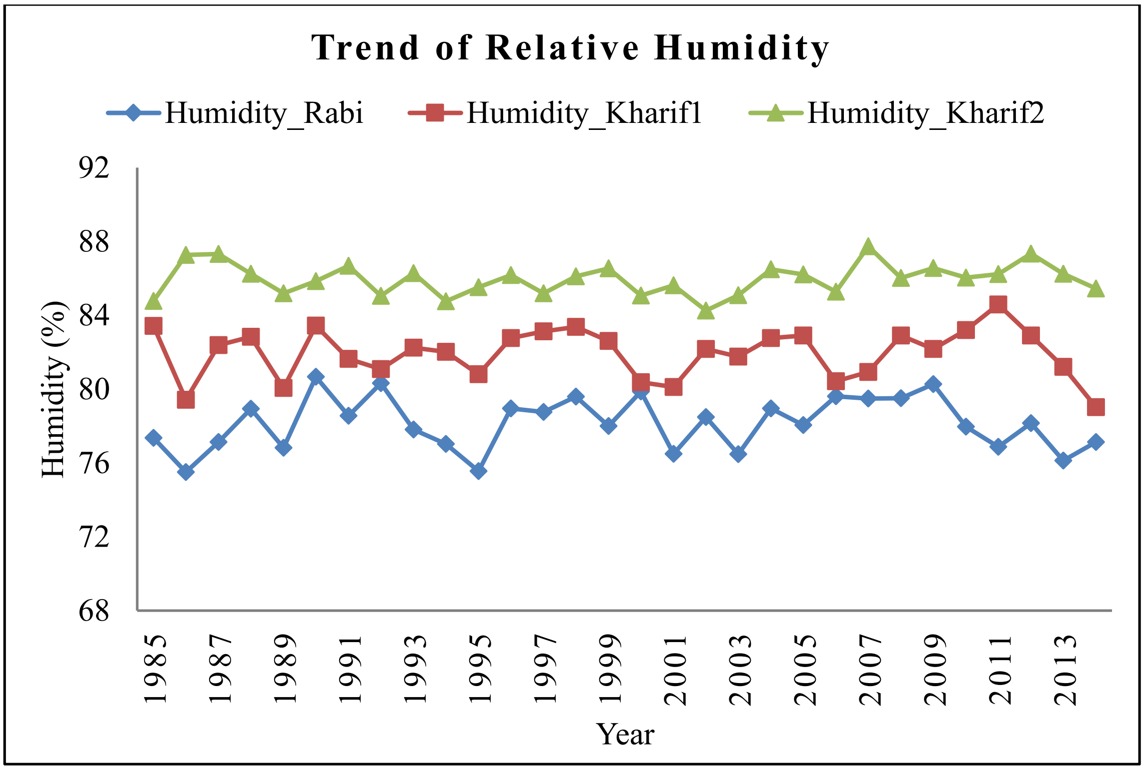


Figure 3.20: Trend and variation of mean relative humidity in three growing seasons.

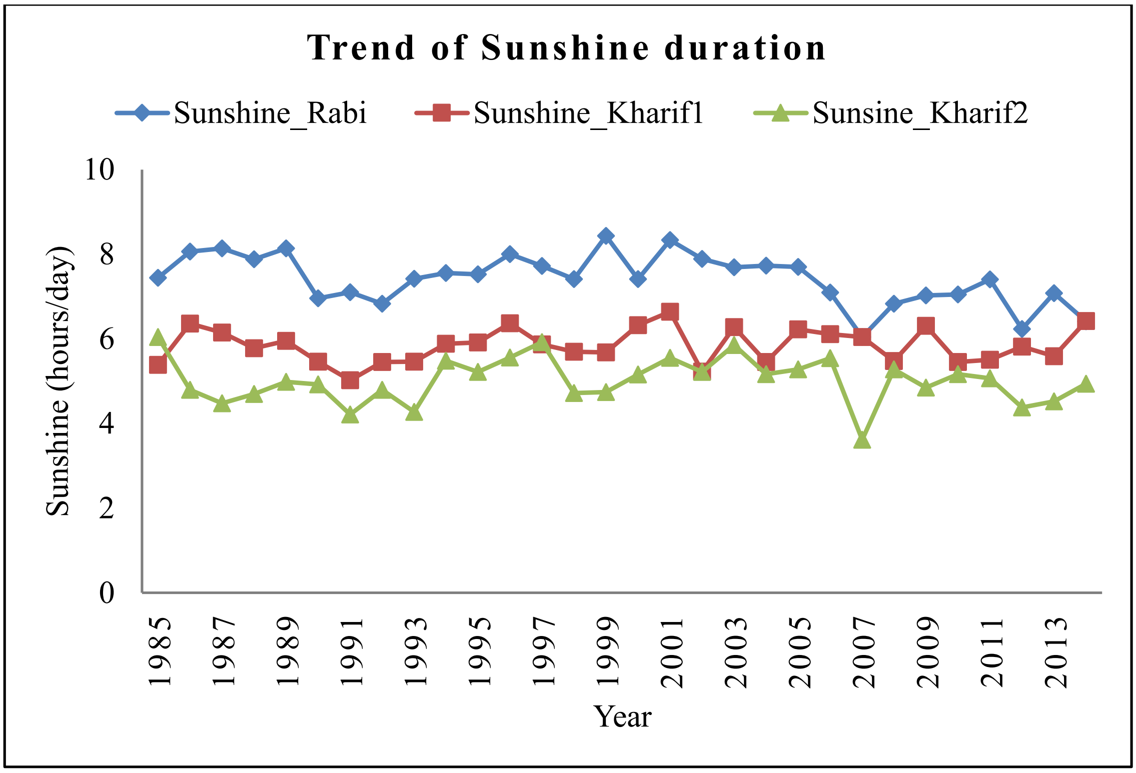


Figure 3.21: Trend and variation of mean sunshine duration in three growing seasons.

3.2 Crop yield-climate relationship

3.2.1 Descriptive statistics of major crops' yield

Table 3.5: Descriptive Statistics of Five major Crops' Yield in Greater Noakhali Region.

	Major Crops' Yield (kg/acre) for the 1985-2014 Period				
	Aus	Aman	Boro	Pulse	Groundnut
Mean	631.71	854.92	1330.31	378.54	588.65
S.D.	71.21	64.45	217.56	53.33	76.89
CV (%)	11.27	7.54	16.35	14.09	13.06
Kurtosis	-1.14	-0.83	-1.11	0.37	1.66
Skewness	0.26	-0.11	0.47	0.85	-1.11
Minimum	514.09	737.4	1026.75	298.41	350.11
Maximum	761.51	975.84	1716.11	521.75	694.48

Source: Authors' own calculation based on DAE (2015).

The descriptive statistics of five major crops' yield (Table 3.5) indicated that the mean yield of Boro rice was the highest, more than 3.5 times higher than that of Pulse, the lowest yield crop in the study area. Moreover, among three rice crops, Boro produced the highest yield, more than two times higher than that of Aus. The value of CV demonstrates that the highest yield variability was found in Boro rice whereas the lowest variability in yield was observed in Aman rice over the period, 1985-2014.

3.2.2 Results of multiple regression model

3.2.2.1 Boro yield model

Regression equation for Boro yield model:

$LnY_{Borot} = \alpha + \beta_1 MaxT_t + \beta_2 MinT_t + \beta_3 Rain_t + \beta_4 RHumid_t + \beta_5 Sunshine_t + \epsilon_t$

Where, Y_{Boro}= Yield of Boro rice in kg/acre

α = Constant term

$MaxT_t$= Average maximum temperature in Rabi season (Mid-Oct to Mid-March)

$MinT_t$ = Average minimum temperature in Rabi season

$Rain_t$ = Total Rainfall in Rabi season

$RHumid_t$ = Average Relative Humidity in Rabi Season

$Sunshine_t$= Average Sunshine duration in Rabi Season

ϵ_t= Error term

t = Time (year)

The OLS method was administered to identify the impacts of climate variables on the yield of Boro rice. The results are presented in Table 3.6 which revealed that the overall Boro yield model was statistically significant at 1% level indicating that the climate variables are able to explain significant variation in Boro rice production. Among climate variables, minimum temperature, rainfall and relative humidity found to be statistically significant at 6%, 1% and 10% level respectively. The R^2 value indicated that 52.2% of the variation in Boro rice yield was influenced by climate variability and change. The regression coefficients demonstrated that minimum temperature, rainfall and relative humidity exhibited significant effect on Boro yield whereas maximum temperature and sunshine expressed no significant influence. Moreover, Boro yield was positively

Table 3.6: Regression results of Boro yield model with necessary test statistics

Model summary: Boro yield model					
Model	R	R Square	Adjusted R Square	Std. Error	Durbin-Watson
Boro Yield	0.723	0.522	0.418	0.0468	2.323

ANOVA					
Model	Sum of Squares	df	Mean square	F	Sig.
Regression	0.055	5	0.011	5.025	0.003
Residuals	0.05	23	0.002		
Total	0.105	28			

Coefficients							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	0.013	0.009		1.473	0.154		
Rabi MaxT	-0.03	0.021	-0.379	-1.416	0.17	0.29	3.448
Rabi MinT	0.042	0.021	0.51	1.952	0.063	0.305	3.279
Rabi Rain	0.00028	0.0001	0.471	2.623	0.015	0.644	1.552
Rabi RHumid	-0.014	0.008	-0.45	-1.671	0.108	0.286	3.494
Rabi Sunshine	0.026	0.022	0.262	1.169	0.254	0.414	2.417
Dependent Variable: LnBoroy							

Heteroskedasticity checking: (H_0 = Homoskedasticity or no heteroskedasticity)			
Breusch-Pagan Test		Koenker Test	
LM	P Value (Sig)	LM	P Value (Sig)
1.963	0.854	3.123	0 .681

Test of normality for regression residuals: (H_0 = Data are normally distributed)						
	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig	Statistic	df	Sig
Standardized Residual	0.105	29	0.2	0.963	29	0.387

influenced by minimum temperature, rainfall and sunshine and negatively influenced by maximum temperature and relative humidity. The regression diagnostic tests (Table 3.6), clearly specified that the model was not suffered from the problem of heteroskedasticity (Breusch-Pagan: p>0.05; Koenker: p>0.05 and Figure 3.22), autocorrelation and multicollinearity (Tolerance>0.2 and VIF<5). On the other hand, Shapiro-Wilk (p>0.05) and Kolmogorov-Smirnov test (p>0.05) and histogram (Figure 3.23) indicated the normal distribution pattern of regression residuals in the model. In general, the basic assumptions of multiple regression were met in the model.

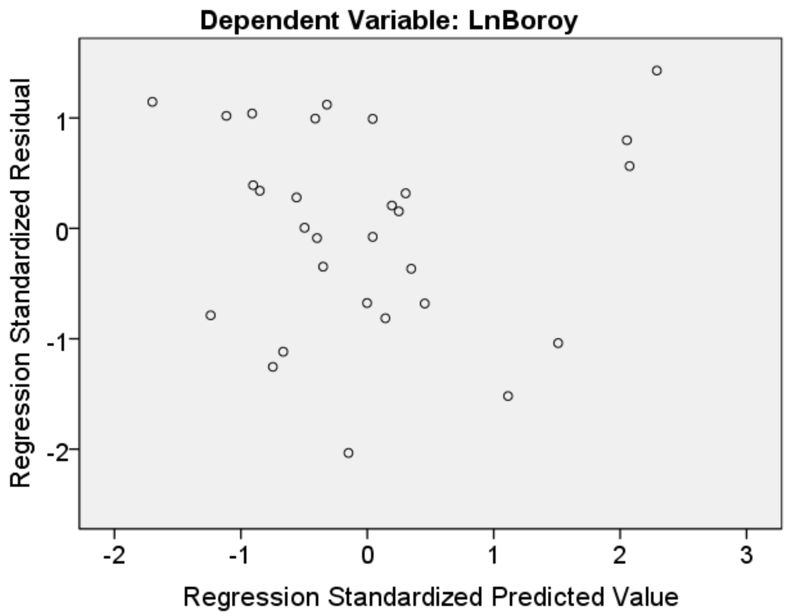


Figure 3.22: Scatterplot showing evidence of homoskedasticity (no heteroskedasticity)

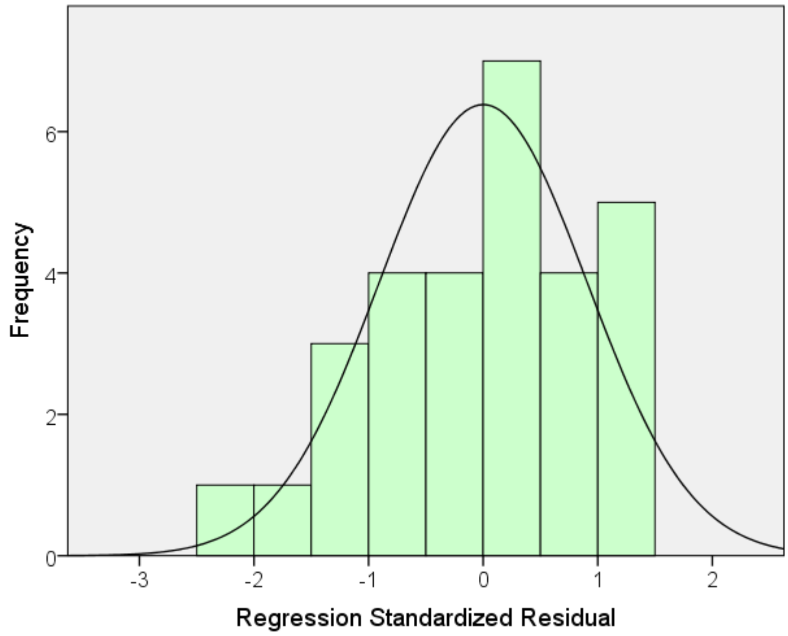


Figure 3.23: Histogram showing normal distribution of regression residuals.

3.2.2.2 Aman yield model

<u>Regression equation for Aman yield model:</u>

$LnY_{Amant} = \alpha + \beta_1 LnMaxT_t + \beta_2 LnMinT_t + \beta_3 LnRain_t + \beta_4 LnRHumid_t + \beta_5 LnSunshine_t + \epsilon_t$

Where, Y_{Aman}= Yield of Aman rice in kg/acre

α = Constant term

$MaxT_t$= Average maximum temperature in Kharif-2 season (Mid-July to Mid-October)

$MinT_t$ = Average minimum temperature in Kharif-2 season

$Rain_t$ = Total Rainfall in Kharif-2 season

$RHumid_t$ = Average Relative Humidity in Kharif-2 Season

$Sunshine_t$= Average Sunshine duration in Kharif-2 Season

ϵ_t= Error term

t = Time (year)

Table 3.7: Regression results of Aman yield model with necessary test statistics

Model summary: Aman yield model

Model	R	R Square	Adjusted R Square	Standard Error	Durbin-Watson
Aman Yield	0.649	0.421	0.295	0.06085	2.211

ANOVA

Model	Sum of Squares	df	Mean square	F	Sig.
Regression	0.062	5	0.012	3.346	0.02
Residuals	0.085	23	0.004		
Total	0.147	28			

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	0.007	0.011		0.602	0.553		
lnK2MaxT	0.853	1.548	0.164	0.551	0.587	0.282	3.54
lnK2MinT	-1.525	1.279	-0.283	-1.192	0.245	0.447	2.239
lnK2Rain	-0.013	0.053	-0.057	-0.243	0.81	0.451	2.218
lnK2RHumid	1.115	1.148	0.238	0.971	0.342	0.419	2.385
lnk2Sunshine	0.291	0.134	0.617	2.175	0.04	0.312	3.2

Dependent Variable: LnAmany

Heteroskedasticity checking: (H_0 = Homoskedasticity or no heteroskedasticity)

Breusch-Pagan Test		Koenker Test	
LM	P Value (Sig)	LM	P Value (Sig)
3.965	0.555	2.601	0.761

Test of normality for regression residuals: (H_0 = Data are normally distributed)

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	df	Sig	Statistics	df	Sig
Standardized Residual	0.111	29	0.2	0.937	29	0.084

The contribution of climate variables on the yield of Aman rice was explored by employing OLS method. The results are reported in Table 3.7 which disclosed that the overall Aman yield model was statistically significant at 2% level implying that the climate variables are able to explain considerable variation in Aman yield. On the other hand, of climate variables, sunshine duration was statistically significant at 4% level. The R^2 value indicated that 42.1% of the variation in Aman yield was affected by climate variability and change. The regression coefficients showed that only sunshine duration expressed significant influence on Aman yield. Moreover, Aman yield was benefitted by maximum temperature, relative humidity and sunshine duration while affected by minimum temperature and rainfall. The output of regression diagnostics (Table 3.7) confirmed that the model was not suffered from the problem of heteroskedasticity (Breusch-Pagan: $p>0.05$; Koenker: $p>0.05$ and Figure 3.24), autocorrelation and multicollinearity (Tolerance>0.2 and VIF<5). The normal distribution pattern of regression residuals was satisfied in the model from Shapiro-Wilk ($p>0.05$) and Kolmogorov-Smirnov test ($P>0.05$) and histogram (Figure 3.25). Overall, basic regression assumptions were maintained in the model.

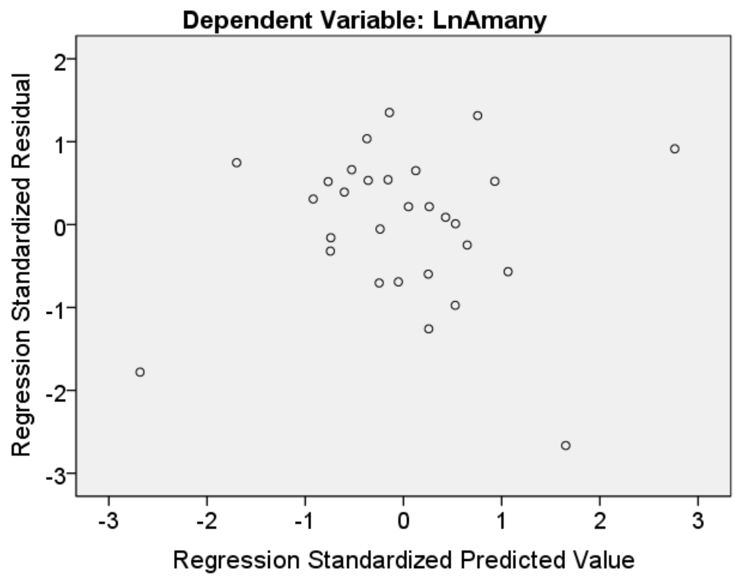


Figure 3.24: Scatterplot showing evidence of homoskedasticity (no heteroskedasticity)

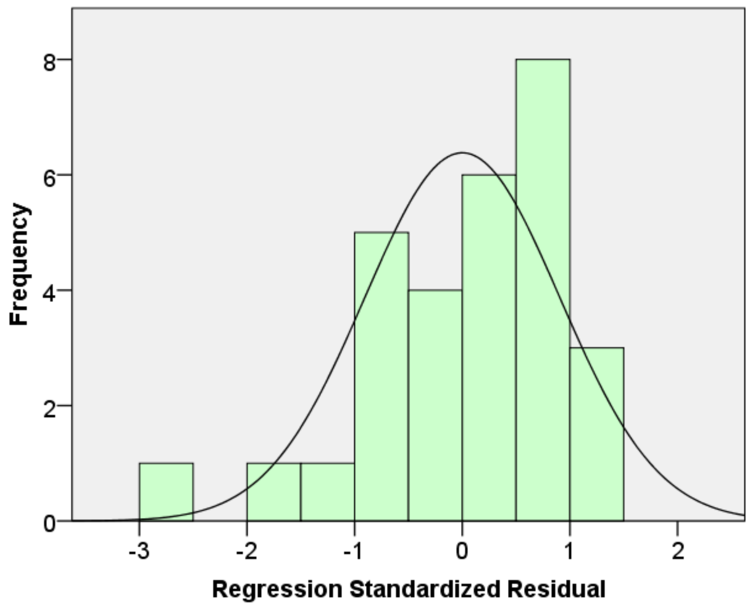


Figure 3.25: Histogram showing normal distribution of regression residuals.

3.2.2.3 Aus yield model

Regression equation for Aus yield model:

$LnY_{Aust} = \alpha + \beta_1 MaxT_t + \beta_2 MinT_t + \beta_3 Rain_t + \beta_4 RHumid_t + \beta_5 Sunshine_t + \epsilon_t$.

Where, Y_{Aus}= Yield of Aus rice in kg/acre

α = Constant term

$MaxT_t$= Average maximum temperature in Kharif-1 season (Mid-March to Mid-July)

$MinT_t$ = Average minimum temperature in Kharif-1 season

$Rain_t$ = Total Rainfall in Kharif-1 season

$RHumid_t$ = Average Relative Humidity in Kharif-1 Season

$Sunshine_t$= Average Sunshine duration in Kharif-1 Season

ϵ_t= Error term

t = Time (year)

The ordinary least square regression method was employed to determine the nexus between major climate variables and Aus rice yield. The findings are presented in Table 3.8 which revealed that the Aus yield model was highly significant at 1% level indicating that the climate variables are able to explain substantial variations in Aus rice yield.

According to the model results, maximum temperature and relative humidity appeared to be statistically significant climate variables at 1%, and 10% level respectively. The R^2 value described that 53.8% of the variation in Aus yield was influenced by climate variability and change. The regression coefficients denoted that maximum temperature and relative humidity contributed significantly to the Aus yield while minimum temperature, rainfall and sunshine seemed to have no significant contribution. More importantly, Aus yield was positively influenced by maximum temperature, minimum temperature, rainfall and relative humidity while negatively influenced by sunshine

Table 3.8: Regression results of Aus yield model with necessary test statistics

Model summary: Aus yield model

Model	R	R Square	Adjusted R Square	Standard Error	Durbin-Watson
Aus Yield	0.734	0.538	0.442	0.0838	1.217

ANOVA

Model	Sum of Squares	df	Mean square	F	Sig.
Regression	0.196	5	0.039	5.594	0.001
Residuals	0.169	24	0.007		
Total	0.365	29			

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	-1.248	1.871		-0.667	0.511		
K1MaxT	0.152	0.046	0.843	3.278	0.003	0.291	3.437
K1MinT	0.021	0.053	0.086	0.407	0.688	0.43	2.326
K1Rain	2.78E-05	0.00008	0.057	0.347	0.732	0.718	1.393
K1RHumid	0.03	0.016	0.357	1.921	0.067	0.556	1.798
K1Sunshine	-0.031	0.048	-0.112	-0.641	0.527	0.628	1.593

Dependent Variable: LnAusy

Heteroskedasticity checking: (H_0 = Homoskedasticity or no heteroskedasticity)

Breusch-Pagan Test		Koenker Test	
LM	P Value (Sig)	LM	P Value (Sig)
1.567	0.905	1.494	0.914

Test of normality for regression residuals: (H_0 = Data are normally distributed)

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	df	Sig	Statistics	df	Sig
Standardized Residual	0.109	30	0.2	0.956	30	0.247

duration. The Aus yield model was not suffered from the problem of heteroskedasticity (Breusch-Pagan: p>0.05; Koenker: p>0.05 and Figure 3.26), autocorrelation and multicollinearity (Tolerance>0.2 and VIF<5) as reported by the regression diagnostics (Table 3.8). Furthermore, Shapiro-Wilk (p>0.05) and Kolmogorov-Smirnov test (p>0.05) and histogram (Figure 3.27) clearly indicated the normal distribution pattern of regression residuals in the model. As a whole, basic regression assumptions were satisfied in the model.

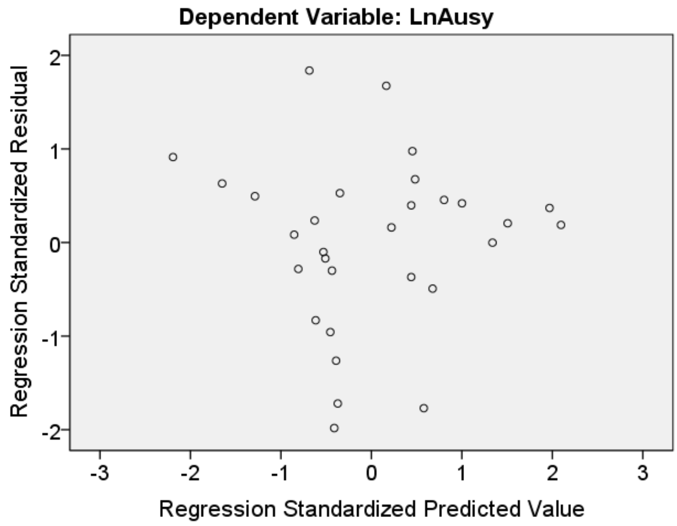


Figure 3.26: Scatterplot showing evidence of homoskedasticity (no heteroskedasticity)

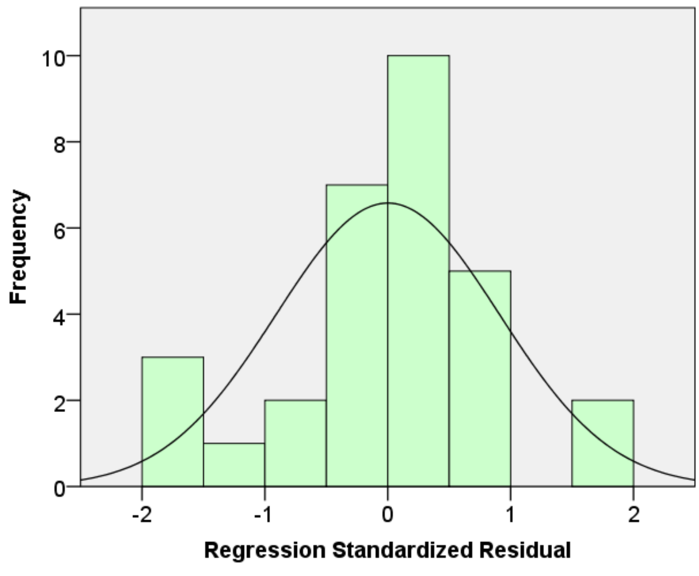


Figure 3.27: Histogram showing normal distribution of regression residuals.

3.2.2.4 Pulse yield model

Regression equation for pulse yield model:

$Y_{Pulset} = \alpha + \beta_1 Rain_t + \beta_2 RHumid_t + \beta_3 Sunshine_t + \epsilon_t$

Where, Y_{Pulse}= Yield of pulse in kg/acre

α = Constant term

$Rain_t$ = Total Rainfall in Rabi season (Mid-Oct to Mid-March)

$RHumid_t$ = Average Relative Humidity in Rabi Season

$Sunshine_t$= Average Sunshine duration in Rabi Season

ϵ_t= Error term

t = Time (year)

Table 3.9: Regression results of pulse yield model with necessary test statistics

Model summary: Pulse yield model

Model	R	R Square	Adjusted R Square	Standard Error	Durbin-Watson
Pulse Yield	0.508	0.258	0.169	44.08935	1.853

ANOVA

Model	Sum of Squares	df	Mean square	F	Sig.
Regression	16886.612	3	5628.871	2.896	0.05
Residuals	48596.763	25	1943.871		
Total	65483.375	28			

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	5.622	8.21		0.685	0.5		
Rabi Rain	-0.114	0.09	-0.242	-1.261	0.219	0.803	1.25
Rabi RHumid	13.607	5.848	0.548	2.327	0.028	0.536	1.87
Rabi Sunshine	49.254	17.262	0.629	2.853	0.009	0.612	1.64

Dependent Variable: Pulsey

Heteroskedasticity checking: (H_0 = Homoskedasticity or no heteroskedasticity)

Breusch-Pagan Test		Koenker Test	
LM	P Value (Sig)	LM	P Value (Sig)
3.287	0.35	2.544	0.467

Test of normality for regression residuals: (H_0 = Data are normally distributed)

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	df	Sig	Statistics	df	Sig
Standardized Residual	0.145	29	0.122	0.969	29	0.53

The effect of climate variables on pulse yield was investigated by applying least square regression method. The results are outlined in Table 3.9 which indicated that the pulse yield model was statistically significant at 5% level meaning that the climate variables are able to explain some variations in pulse yield. Of major climate variables, relative humidity and sunshine duration found to be statistically significant at 3% and 1% level respectively. The R^2 value explained that 25.8% variation in pulse yield was influenced by climate variables. The regression coefficients demonstrated that pulse yield was significantly influenced by relative humidity and sunshine duration and insignificantly influenced by rainfall. More particularly, relative humidity and sunshine duration expressed positive influence on pulse yield whereas rainfall expressed negative influence on it. The regression diagnostics (Table 3.9) evidenced that the model was not encountered the problem of heteroskedasticity (Breusch-Pagan: $p>0.05$; Koenker: $p>0.05$ and Figure 3.28), autocorrelation and multicollinearity (Tolerance>0.2 and VIF<5). The normal distribution pattern of regression residuals in the model was supported by Shapiro-Wilk ($p>0.05$) and Kolmogorov-Smirnov test ($p>0.05$) and histogram (Figure 3.29). In general, the above test statistics suggested that basic assumptions of multiple regression were fulfilled in the model.

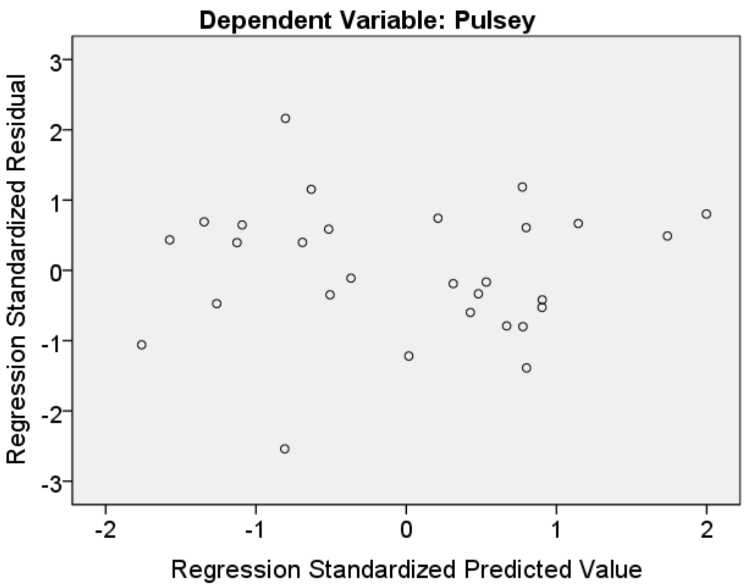


Figure 3.28: Scatterplot showing evidence of homoskedasticity (no heteroskedasticity)

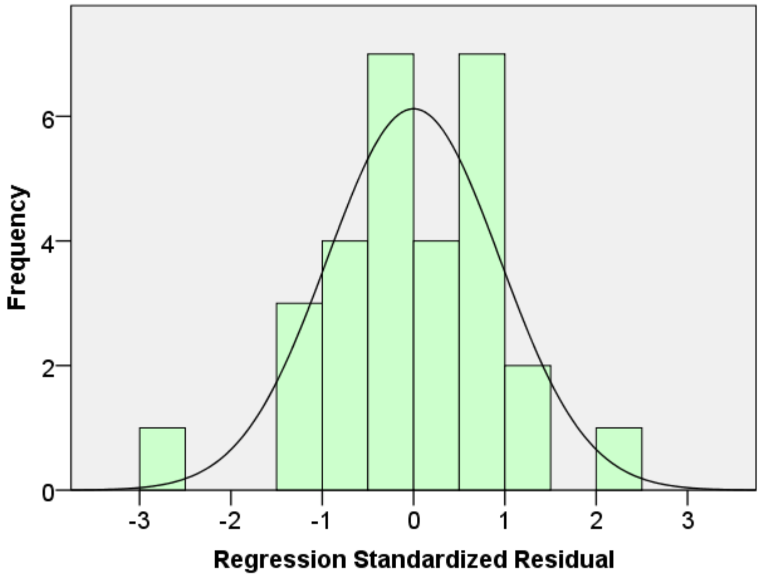


Figure 3.29: Histogram showing normal distribution of regression residuals.

3.2.2.5 Groundnut yield model

Regression equation for groundnut yield model:

$LnY_{Groundnutt} = \alpha + \beta_1 MinT_t + \beta_2 Rain_t + \beta_3 Sunshine_t + \epsilon_t$

Where, $Y_{Groundnut}$= Yield of groundnut in kg/acre

α = Constant term

$MinT_t$ = Average Minimum temperature in Rabi season (Mid-Oct to Mid-March)

$Rain_t$ = Total Rainfall in Rabi Season

$Sunshine_t$= Average Sunshine duration in Rabi Season

ϵ_t= Error term

t = Time (year)

The impact of climate variables on groundnut yield was estimated by using ordinary least square regression method. The regression output demonstrated that the overall groundnut yield model was statistically significant at 8% level denoting that the climate variables are able to capture some variations in groundnut yield (Table 3.10). Of three climate variables included in the model, sunshine duration was statistically significant at 2% level. The R^2 value specified that 23.1% variation in groundnut yield was influenced by climatic variables. The regression coefficients denoted that that groundnut yield was significantly influenced by sunshine duration and insignificantly influenced by minimum temperature and rainfall. Moreover, minimum temperature positively contributed to the groundnut yield while rainfall and sunshine negatively contributed to the yield. The regression diagnostics (Table 3.10) documented that the model was not suffered from the problem of heteroskedasticity (Breusch-Pagan: p>0.05; Koenker: p>0.05 and Figure 3.30), autocorrelation and multicollinearity (Tolerance>0.2 and VIF<5). The Shapiro-Wilk (p>0.05) and Kolmogorov-Smirnov test (p>0.05) and histogram (Figure 3.31) clearly

Table 3.10: Regression results of Groundnut yield model with necessary test statistics

Model summary: Groundnut yield model

Model	R	R Square	Adjusted R Square	Standard Error	Durbin-Watson
Groundnut Yield	0.481	0.231	0.139	0.09193	1.878

ANOVA

Model	Sum of Squares	df	Mean square	F	Sig.
Regression	0.064	3	0.021	2.506	0.082
Residuals	0.211	25	0.008		
Total	0.275	28			

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	-0.003	0.017		-0.152	0.88		
Rabi MinT	0.048	0.029	0.358	1.627	0.116	0.635	1.574
Rabi Rain	-0.00027	0.0002	-0.282	-1.301	0.205	0.656	1.524
Rabi Sunshine	-0.071	0.029	-0.439	-2.45	0.022	0.956	1.046
Dependent Variable: LnGroundnuty							

Heteroskedasticity checking: (H_0 = Homoskedasticity or no heteroskedasticity)

Breusch-Pagan Test		Koenker Test	
LM	P Value (Sig)	LM	P Value (Sig)
2.11	0.55	1.508	0.68

Test of normality for regression residuals: (H_0 = Data are normally distributed)

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	df	Sig	Statistics	df	Sig
Standardized Residual	0.151	29	0.089	0.944	29	0.13

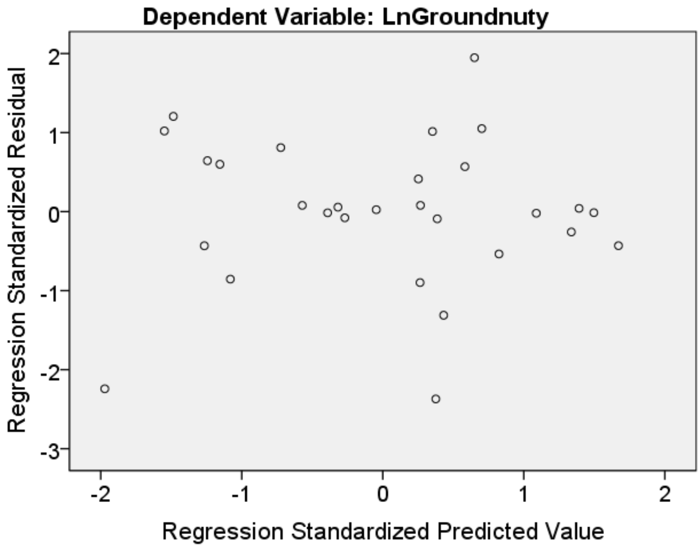


Figure 3.30: Scatterplot showing evidence of homoskedasticity (no heteroskedasticity)

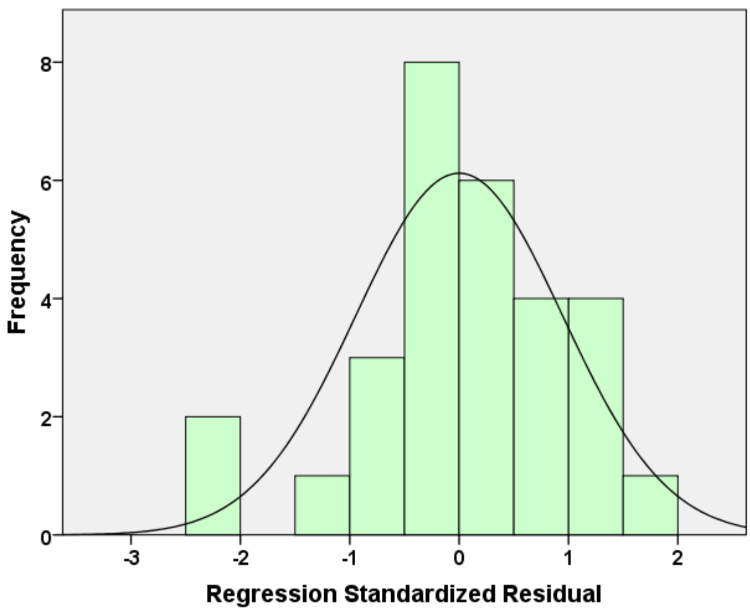


Figure 3.31: Histogram showing normal distribution of regression residuals.

specified the normal distribution of regression residuals in the model. The overall test results supported that basic regression assumptions were satisfied in the model.

Table 3.11: The overall regression results of five major crops' yield

Independent Variables	Dependent Variables				
	Boro Rice	Aman Rice	Aus Rice	Pulse	Groundnut
Maximum Temperature	-0.03	0.853	0.152***	-	-
Minimum Temperature	0.042*	-1.525	0.021	-	0.048
Rainfall	0.00028**	-0.013	2.78E-05	-0.114	-0.00027
Relative Humidity	-0.014*	1.115	0.030*	13.607**	-
Sunshine Duration	0.026	0.291**	-0.031	49.254***	-0.071**
Intercept	0.013	0.007	-1.248	5.622	-0.003
Model R^2	0.522	0.421	0.538	0.258	0.231
Adjusted R^2	0.418	0.295	0.442	0.169	0.139
Significance (P value)	0.003	0.02	0.001	0.05	0.08

***,**,* Significant at 1%, 5%, and 10% probability level, respectively.

3.3 Cropping pattern change and causes

3.3.1 Cropping pattern change

3.3.1.1 Evidence from historical data

The empirical results revealed that significant change in historical cropping pattern was occurred in the study area (Table 3.12 and Figure 3.32). Main cropping pattern in 1985-1994 decade was Aman, Aus & Boro rice, pulse, groundnut, green chili, winter vegetables and sweet potato in terms of total cropping area while it shifted to Aman, Boro & Aus rice, soyben, pulse, groundnur, winter vegetables, green chili and sweet potato in 2005-2014 decade. Major changes in cropping pattern during the period include the cropping area increment of Boro rice, soybean, pulse, groundnut and winter vegetables and decrement of Aus rice, green chili and sweet potato (Table 3.12). It was also noticed that Boro rice shifted its position from 3rd to 2nd, Aus rice from 2nd to 3rd, Pulse from 4th to 5th and Groundnut from 5th to 6th rank. The most pronounced change in cropping pattern was

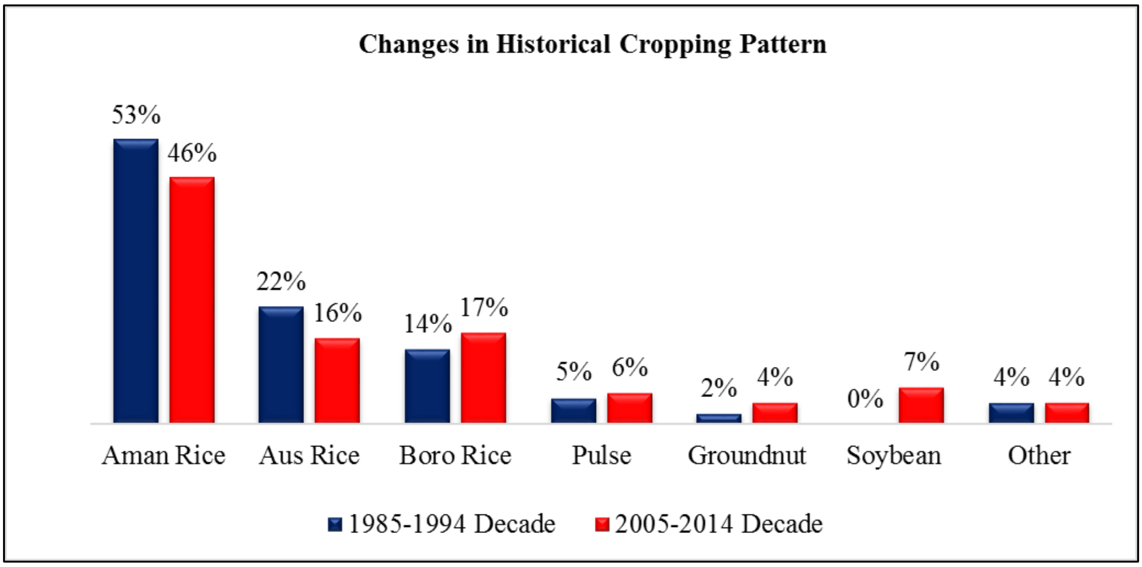


Figure 3.32: Changes in historical cropping pattern between 1985-1994 and 2005-2014.

the introduction of soybean which occupied the 4th position in major cropping pattern. In terms of percentage of total cropped area, it was observed that Aman and Aus rice decreased from 53% to 46% and 22% to 16% while Boro rice and soybean increased from 14% to 17% and 0% to 7% respectively within two decades (Figure 3.32).

Table 3.12: Changes in cropping pattern in three decades in Greater Noakhali Region.

Time	**Major Crops of Greater Noakhali Region**									
1985-1994	Major Crop	Aman Rice	Aus Rice	Boro Rice	Pulse	Ground Nut	Green Chili	Winter Vegetable	Sweet Potato	Wheat
	Area ('000 ha)	3076.13	1258.53	788.30	266.09	117.35	104.34	62.76	58.53	16.55
1995-2004	Major Crop	Aman Rice	Aus Rice	Boro Rice	Pulse	Ground Nut	Green Chili	Winter Vegetable	Sweet Potato	Soy Bean
	Area ('000 ha)	3070.99	952.53	949.05	247.89	173.39	75.02	73.93	55.32	35.62
2005-2014	Major Crop	Aman Rice	Boro Rice	Aus Rice	Soy Bean	Pulse	Ground Nut	Winter Vegetable	Green Chili	Sweet Potato
	Area ('000 ha)	3109.58	1127.68	1107.91	458.68	414.05	242.37	119.21	72.61	56.57

3.3.1.2 Evidence from questionnaire data

The questionnaire survey result provided us an evidence of significant cropping pattern change in the adjacent coastal sub-district, Ramgoti of the region (Figure 3.33: a & b). In the past (3 decades ago), major cropping patterns in the sub-district comprised Aus-Aman-Pulse (33%), Aus-Aman-Green Chilli (26%) and Aus-Aman-Groundnut (22%), etc. Presently (in the last decade), it is shifted to Aus-Aman-Soybean (40%) followed by Fallow-Aman-Soybean (34%) and Aus-Aman-Winter Vegetables (8%), etc.

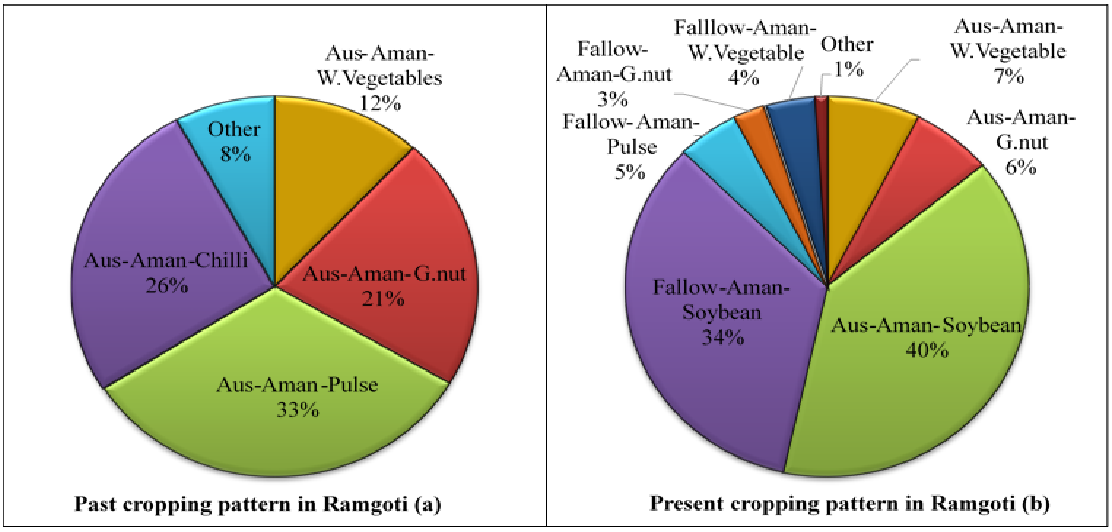


Figure 3.33 (a & b): Past and present cropping pattern in Ramgoti according to survey.

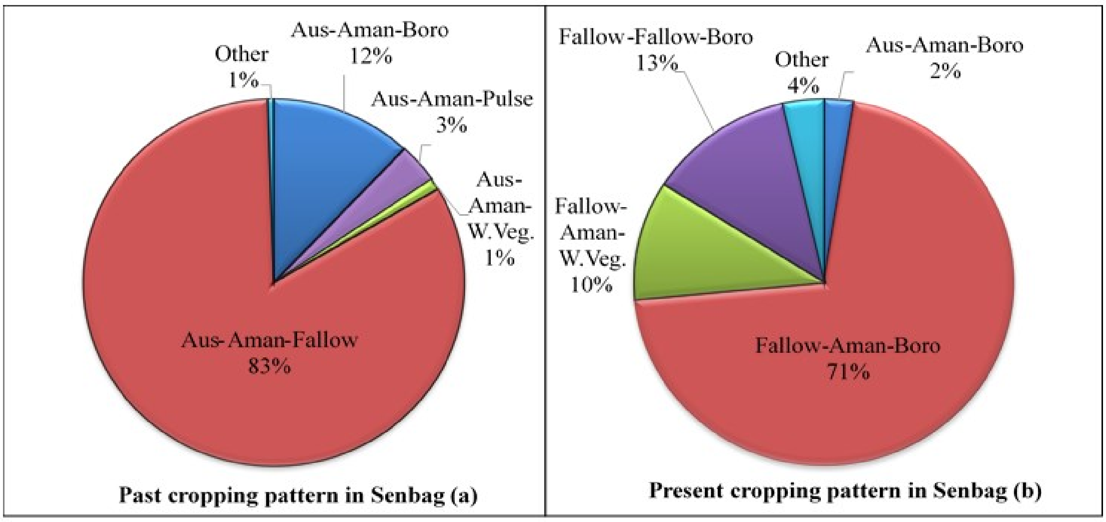


Figure 3.34 (a & b): Past and present cropping pattern in Senbag according to survey.

Considerable changes in cropping pattern was also reported in the non-adjacent coastal sub-disrict, Senbag of the region according to the questionnaire survey result (Figure 3.34: a & b). In earlier times (3 decades ago), dominant cropping patterns in the area involved Aus-Aman-Fallow (83%), Aus-Aman-Boro (12%) and Aus-Aman-Pulse (4%), etc. Presently (in the last decade), it is changed to Fallow-Aman-Boro (71%) followed by Fallow-Fallow-Boro (13%) and Fallow-Aman-Winter Vegetables (11%), etc.

3.3.2 Causes of cropping pattern change

The questionnaire survey and FGDs documented that climate change (75%) is mainly responsible for cropping pattern change in the study area although the effect of non-climatic factors cannot be ignored (Figure 3.35). In contrast, farmers of 25% claimed that both climatic and non-climatic factors are equally responsible for cropping pattern change while 5% farmers responded non-climatic factors as the principal cause of change in cropping pattern.

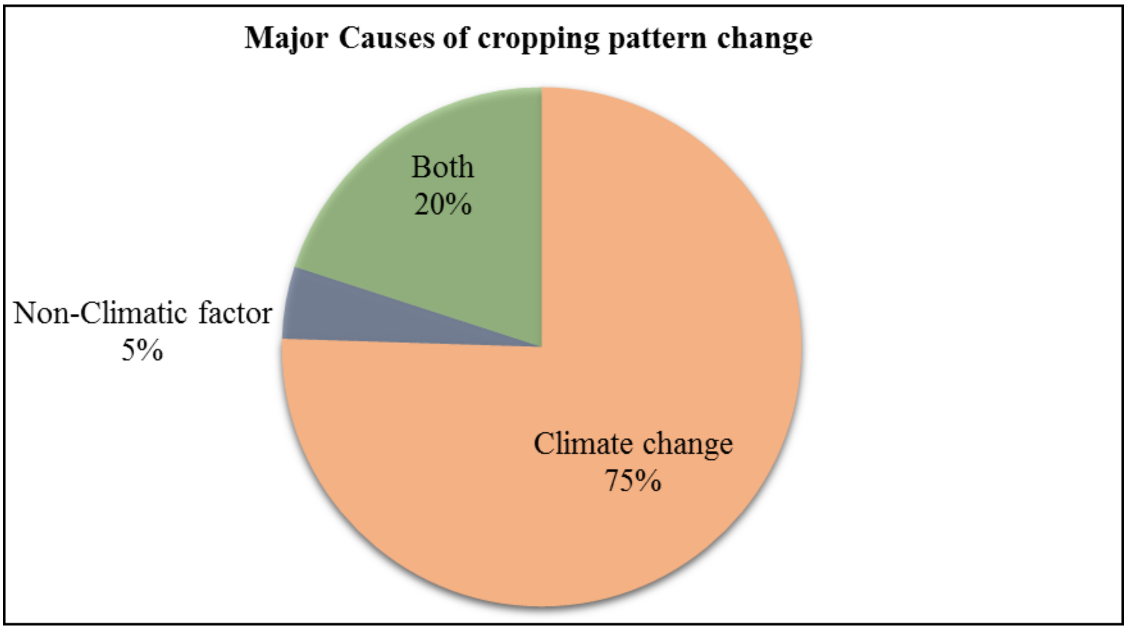


Figure 3.35: Major causes of cropping pattern change in the study area.

Of the non-climatic factors that affect crop sequences, the proportion of the high yielding varieties was estimated to be the highest (32%) followed by high profitability (19%), development of entrepreneurship (4%), expansion of agricultural education (6%), increased government support (4%), reduced water availability (4%), changed demand for food crops (12%), etc. (Figure 3.36).

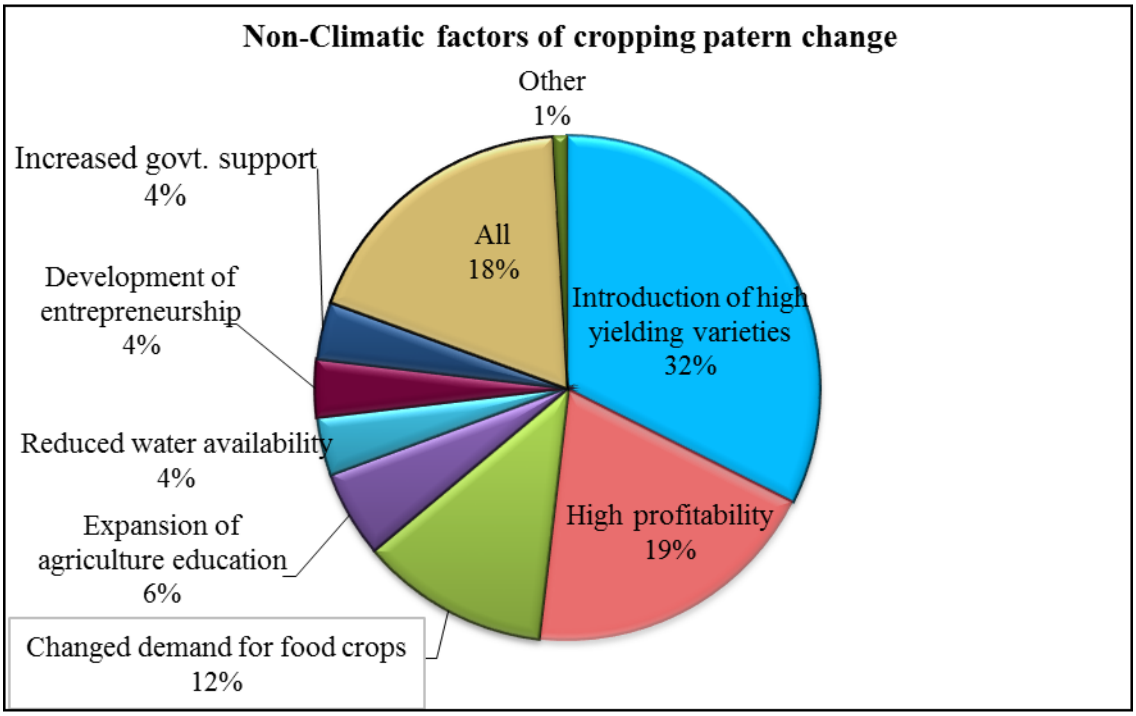


Figure 3.36: Non-Climatic factors of cropping pattern change according to survey result

3.4 Farmers' adaptation options and its determinants

3.4.1 Farmers' perception on climate change

The study also identified farmers' perceptions on climate change. This is very crucial as farmers' first need to recognize climate change before they can adopt adaptation strategies in order to lessen their vulnerability due to climate change. According to questionnaire survey, most of the farmers in the study area (97%) documented an increase in temperature (warmer climate) presently than 3 decades ago (Figure: 3.37a). On the other hand, farmers perceived a reduction in the amount of rainfall in compared to 3 decades before (Figure: 3.37b). Furthermore, farmers also recognized a decrease in the amount of sunshine (86%) currently than 3 decades ago (Figure: 3.37c). These findings are consistent with the trend of historical time series climate data.

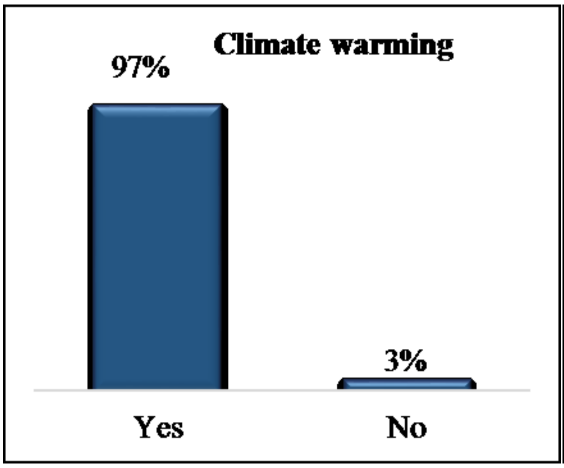


Fig. 3.37 (a)

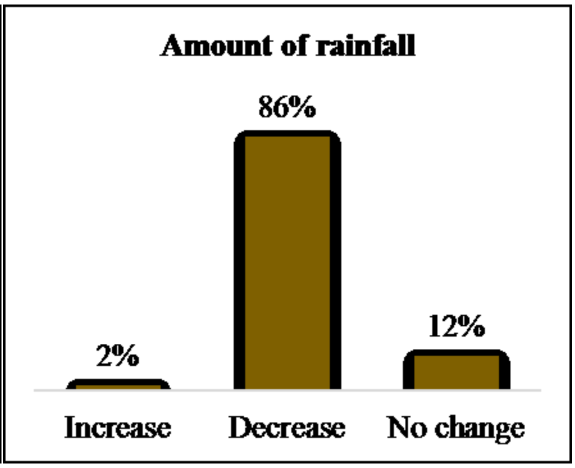


Fig. 3.37 (b)

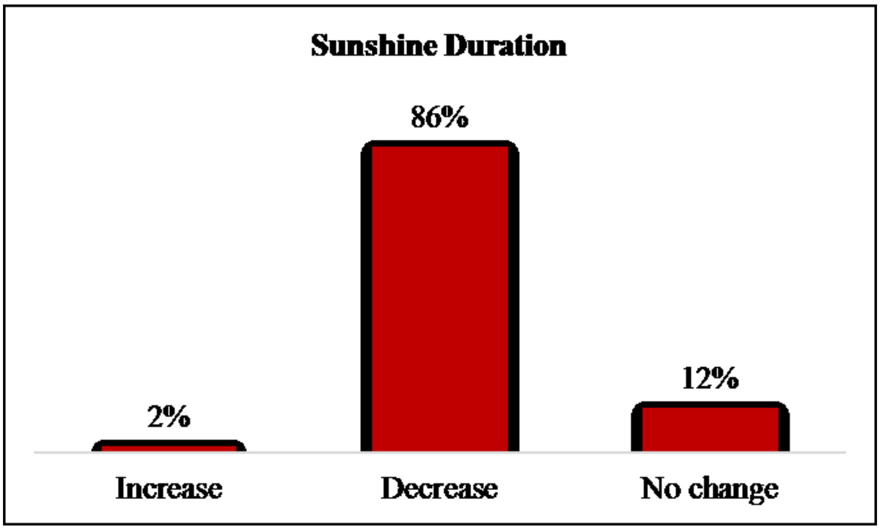
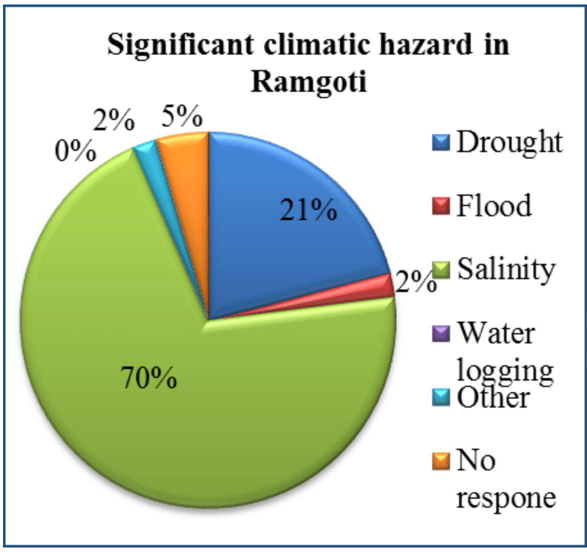


Fig.3.37 (c)

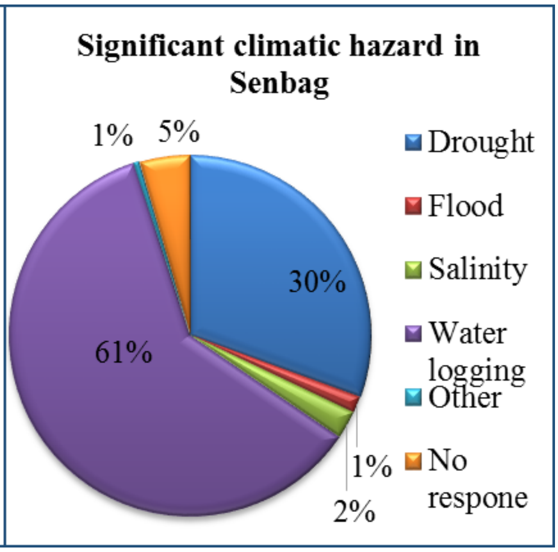
Figure 3.37: Farmers' perception on change in different climate parameters: (a) temperature, (b) amount of rainfall and (c) sunshine hours.

3.4.2 Farmers' perception on climatic hazards

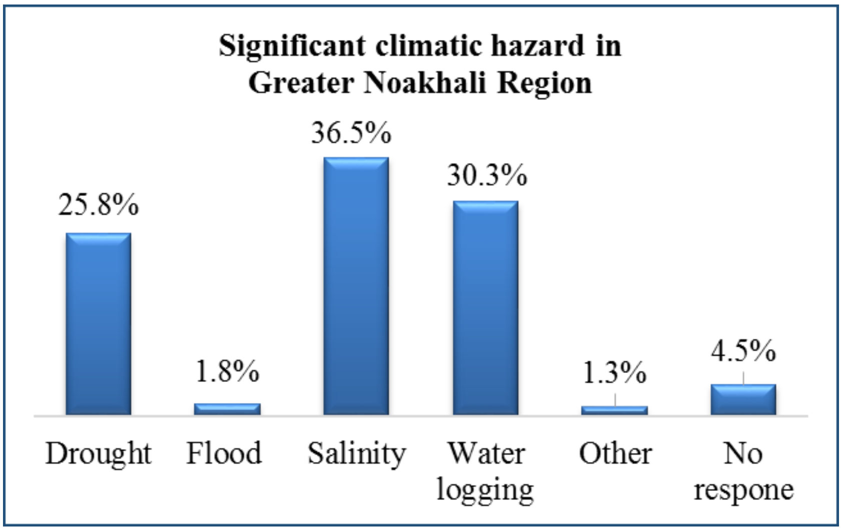
According to the questionnaire survey result, the most significant climatic hazard on crop production in Ramgoti, the adjacent coastal sub-district appeared to be salinity intrusion (70%) whereas the most pronounced climatic hazard in Senbag, the non-adjacent coastal sub-district found to be water logging (61%) [Figure: 3.38 (a & b)]. In general, the three most important climatic hazards that revealed from the farmers' survey included salinity intrusion (36.5%), water logging (30.3%) and drought (25.8%) which affect the crop agriculture in the region greatly (Figure :3.38c).



(a)



(b)

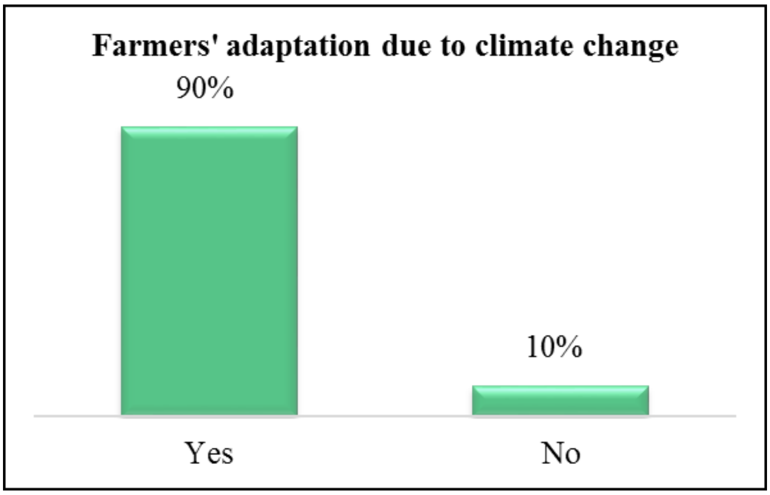


(c)

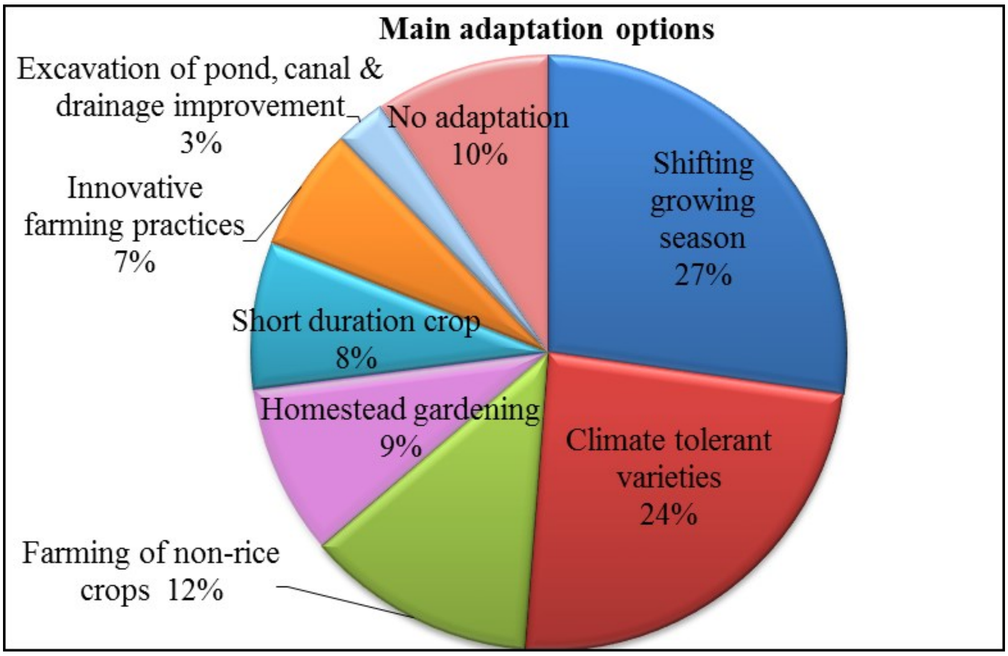
Figure 3.38: Significant climatic hazard on crop production in: (a) Ramgoti, (b) Senbag and (c) Overall Greater Noakhali Region.

3.4.3 Adaptation options, adjustment and barriers to adaptation

The questionnaire survey reported that 90% farmers (n=400) adopted adaptation measures while the remaining 10% farmers undertaken no adaptation choices in the study



(a)

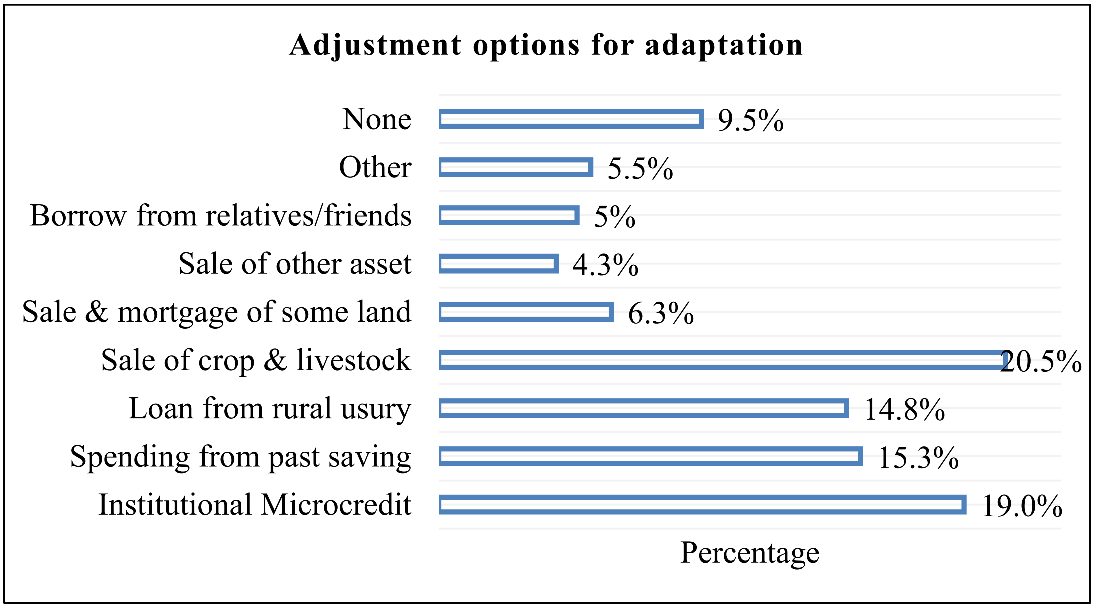


(b)

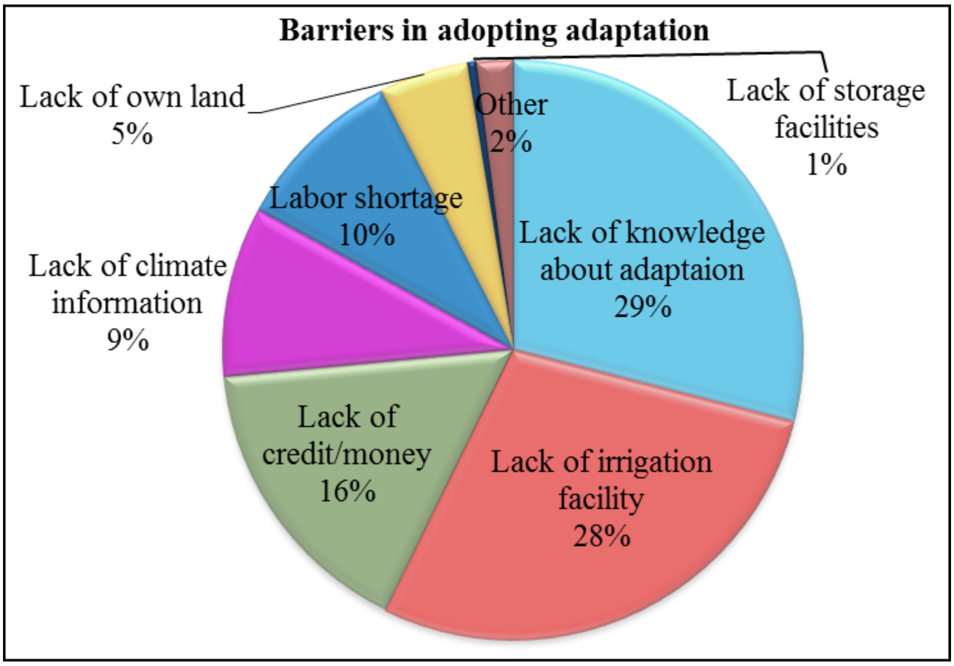
Figure 3.39: (a) Adaptation rate of the farmers due to climate change, (b) Main adaptation strategies practiced in the study area.

area (Figure 3.39a). The most common adaptation option practiced by the farmers was shifting growing season (27%) (Figure 3.39b). The other main adaptation options exercised by the farmers include the introduction of climate tolerant varieties (24%) such as drought, saline and flood tolerant crop varieties, farming of non-rice crops (12%) such as groundnut, pulses, soybean, green chili, vegetables, etc., agroforestry and homestead gardening (9%), planting short duration crop (8%), innovative farming practices such as mulching (7%) and excavation of pond, canal and drainage improvement (3%).

Adaptive options might fix one problem but they sometimes generate other problems which require an adjustment to adaptations. It was disclosed that farmers in the study area adapted to some adjustment measures in accomplishing adaptation (Figure 3.40a). The prime adjustment methods undertaken by the farmers involve the sale of crops and livestock (20.5%), taking institutional micro-credit (19%), taking loans from rural usury (14.8%), spending money from past savings (15.3%), sale or mortgage of some land (6.3%), borrowing money from relatives and friends (5%), sale of other assets (4.3%) and others (5.5%). On the other hand, 9.5% households adopted no measures for adjustment.



(a)



(b)

Figure 3.40: (a) Farmers' adjustment options for adaptation, (b) Barriers in adopting adaptation measures in the study area.

The major barriers and challenges encountered by the farmers in implementing adaptations (Figure 3.40b) consist of lack of knowledge concerning appropriate adaptation method (29%), inadequate irrigation facilities (28%), credit constraints (16%), shortage of labor (10%), unavailability of climate information on time (9%), lack of land ownership (5%), insufficient storage facilities (1%) and others (2%).

3.4.4 Determinants of farmers' choice of adaptation methods: evidence from MNL model:

3.4.4.1 Description of the model variables

According to the survey result, mainly eight types of adaptation strategies practiced in the study area including no adaptation. As a result, adaptation choices or response variables involved in the MNL model had eight categories; namely (1) shifting growing season, (2) introduction of climate tolerant varieties, (3) innovative farming practices like mulching,

(4) planting short duration crop, (5) farming of non-rice crops, (6) excavation of pond, canal and drainage improvement, (7) agro-forestry and homestead gardening and (8) no adaptation. Therefore, the dependent variable of the MNL model was the choice of adaptation measure having eight categories or types. The explanatory or independent variables for the study was chosen on the basis of the available literature which include different socio-economic, household, farm and institutional factors (Table 3.13).

The estimation of the multinomial logit model was undertaken by normalizing one category which is normally defined as the reference state or base category. No adaptation was selected as the reference category for this study.

Table 3.13: Description of the explanatory variables.

Variables	**Obs.**	**Mean**	**Std. dev.**	**Description**
Age	400	47.84	12.0000	Continuous (in year)
Experience	400	30.4275	14.8244	Continuous (in year)
Household size	400	6.515	2.1085	Continuous (in number)
Household income	400	168542	93048.35	Continuous (in taka)
Livestock ownership	400	0.64	0.4806	Dummy, takes the value of 1 if owned and 0 otherwise
Tenure status	400	0.6975	0.4599	Dummy, takes the value of 1 if there is and 0 otherwise
Farm size	400	233.015	148.9802	Continuous (in decimal)
Agriculture Extension	400	0.7225	0.4483	Dummy, takes the value of 1 if there is and 0 otherwise
Farmer to farmer extension	400	0.7025	0.4577	Dummy, takes the value of 1 if there is and 0 otherwise
Climate information	400	0.8575	0.35	Dummy, takes the value of 1 if there is and 0 otherwise
Credit access	400	0.475	0.5	Dummy, takes the value of 1 if there is and 0 otherwise
Market distance	400	1.825	1.3446	Continuous (in kilometer)
Education	400	5.665	4.1049	Continuous (in year)
Nonfarm income	400	36322.5	48886.33	Continuous (in taka)

3.4.4.2 Test results for basic assumptions of the model

The MNL model with eight categories of adaptation choices was run and tested for the IIA assumption by applying the Hausman test, Suest based Hausman test and Small Hsiao test. All three tests failed to reject the null hypothesis of independence of the climate change adaptation strategies, indicating that the multinomial logit (MNL) specification is valid to model climate change adaptation choices of farmers' household. χ^2 ranged from 12.462 to 43.004, with p value of 1.00 in the case of the SUEST based Hausman test (Table 3.14) and χ^2 ranging from -821.658 to 110.063, with a P value of 1.00 in the case of Small Hsiao test (Table 3.15). In the case of Hausman test, χ^2 values were less than 0.00 for some omitted variables (Table 3.16). Asymptotic assumptions of the test are not satisfied in the estimated model, as the χ^2 value is less than 0.00. Negative test statistics are merely usual in empirical work (Cheng and Long, 2007). Hausman and McFadden (1984) reported the likelihood and inferred that a negative result was evidence that the IIA assumption had not been violated.

Table 3.14: SUEST-based Hausman test

H_0: Odds (Outcome-J vs Outcome-K) are independent of other alternatives

Omitted variables	**Chi^2**	**df**	**P>chi^2**	**Evidence for H_0**
Shifting growing season	35.975	90	1.000	Yes
Introduction of Climate tolerant varieties	43.004	90	1.000	Yes
Innovative farming practices	20.330	90	1.000	Yes
Short duration crop	26.113	90	1.000	Yes
Farming of non-rice crops	31.280	90	1.000	Yes
Excavation of pond/canal and drainage improvement	12.462	90	1.000	Yes
Agro-forestry and homestead gardening	25.354	90	1.000	Yes
No adaptation	15.745	90	1.000	Yes

Table 3.15: Small Hsiao test

H_0: Odds (Outcome-J vs Outcome-K) are independent of other alternatives

Omitted variables	**lnL(full)**	**lnL(omit)**	**Chi^2**	**df**	**$P>chi^2$**	**Evidence for H_0**
Shifting growing season	-208.548	-619.377	-821.658	105	1.00	Yes
Introduction of Climate tolerant varieties	-213.26	-256.865	-87.209	105	1.00	Yes
Innovative farming practices	-272.99	-256.865	32.251	105	1.00	Yes
Short duration crop	-255.659	-256.865	-2.412	105	1.00	Yes
Farming of non-rice crops	-237.685	-256.865	-38.359	105	1.00	Yes
Excavation of pond, canal and drainage improvement	-275.076	-256.865	36.423	105	1.00	Yes
Agro-forestry and homestead gardening	-255.206	-256.865	-3.317	105	1.00	Yes
No adaptation	-311.896	-256.865	110.063	105	0.348	Yes

Table 3.16: Hausman test

H_0: Odds (Outcome-J vs Outcome-K) are independent of other alternatives

Omitted variables	**Chi^2**	**df**	**$P>chi^2$**	**Evidence for H_0**
Shifting growing season	-5.590	75	1.00	Yes
Introduction of Climate tolerant varieties	12.719	77	1.000	Yes
Innovative farming practices	-1.074	77	1.00	Yes
Short duration crop	3.471	74	1.000	Yes
Farming of non-rice crops	-2.439	77	1.00	Yes
Excavation of pond/canal and drainage improvement	-1.046	77	1.00	Yes
Agro-forestry and homestead gardening	2.710	72	1.000	Yes
No adaptation	0.206	78	1.000	Yes

3.4.4.3 Parameter estimates of the MNL model

Table 3.17: Summary of MNL model

Model summary	
Base outcome	No adaptation
Observation	400
LR chi-square	267.95***
Prob > chi-square	0.0000
Log likelihood	-619.3768
Pseudo- R^2	0.1778

The likelihood ratio statistics as denoted by χ^2 statistics were very significant ($P < 0.00001$), suggesting the model employed had a strong explanatory capabilities (Table 3.17). However, the parameter estimates of the MNL model only demonstrate the direction of the effect of the explanatory variables on the dependent variable (Table 3.18). The actual magnitude of changes or probabilities is not illustrated by the estimates. Therefore, the MNL model parameters were transformed into relative risk ratios (RRR) as they are easy to interpret.

3.4.4.4 Significant determinants of adaptation choices

Since many of the explanatory variables are dummies, the RRR can be described as the relative probability of selecting alternative j to no adaptation which is the reference category (Table 3.19). The outcome of the MNL model revealed that the significant determinants that affect farmers' adaptation choices in the study area include household size, livestock ownership, tenure status (land ownership), farm size, information on climate and access to credit, distance to market, education and nonfarm income. Factors or determinants that were not significant under the MNL model but had an expected association with the adaptation choices include age, experience, household income, agriculture extension and farmer to farmer extension. The most significant factors explored from the model incorporate tenure status, information on climate, access to credit and livestock ownership as the RRR values of these variables are predominantly higher for most of the adaptation categories.

Table 3.18: Parameter estimates of the multinomial logit climate change adaptation model

Adaptive Strategies	Shifting growing season		Introduction of Climate tolerant varieties		Innovative farming practices		Short duration crop		Farming of non-rice crops		Excavation of pond/canal and drainage improvement		Agro-forestry and homestead gardening	
Explanatory variables	Coef.	P level	Coef.	P level	Coef.	P level	Coef.	P level	Coef.	P level	Coef.	P level	Coef.	P level
Age	-0.001	0.980	-0.027	0.605	-0.020	0.733	-0.014	0.802	-0.025	0.649	0.051	0.421	-0.041	0.465
Experience	0.023	0.614	0.040	0.388	0.050	0.336	0.034	0.489	0.052	0.283	0.029	0.584	0.079	0.115
Household size	0.676**	0.024	0.799***	0.008	0.725**	0.022	0.814***	0.008	0.669**	0.029	0.872***	0.008	0.729**	0.018
Household income	0.000015	0.355	0.000017	0.286	3.13e-06	0.853	0.000019	0.270	0.000014	0.408	0.0000216	0.266	8.25e-06	0.632
Livestock ownership	1.270*	0.079	1.380*	0.062	0.948	0.244	1.667**	0.046	1.287*	0.093	0.182	0.857	1.417*	0.072
Tenure status	1.630**	0.048	1.461*	0.082	2.727***	0.006	1.518*	0.108	1.167	0.179	2.469*	0.084	1.913**	0.033
Farm size	0.012*	0.088	0.012*	0.088	0.017**	0.018	0.013*	0.080	0.013*	0.057	0.010	0.276	0.012*	0.100
Agriculture extension	0.425	0.583	0.467	0.555	0.597	0.508	0.127	0.886	-0.002	0.998	0.020	0.987	0.681	0.428
Farmer to farmer extension	-0.502	0.529	-0.240	0.767	0.556	0.561	0.046	0.960	0.471	0.586	0.074	0.948	-0.739	0.384
Climate information	1.502*	0.068	2.041**	0.020	1.048	0.287	1.878*	0.087	2.349**	0.017	-0.335	0.788	1.922**	0.051
Credit access	1.750**	0.041	1.842**	0.033	2.325**	0.013	1.796**	0.051	1.928**	0.030	1.899*	0.078	1.788**	0.048
Market Distance	-0.498*	0.062	-0.574**	0.038	-0.631**	0.050	-0.521*	0.092	-0.553*	0.056	-0.342	0.369	-0.286	0.316
Education	0.299**	0.022	0.253*	0.056	0.223	0.115	0.316**	0.024	0.268**	0.048	0.504***	0.003	0.303**	0.028
Nonfarm income	-.00002*	0.078	-.000019*	0.081	-6.15e-06	0.585	-.00002*	0.091	-.00002*	0.085	-.00003**	0.047	-.0000145	0.219
Constant	-8.89***	0.000	-9.915***	0.000	-11.23 ***	0.000	-12.59 ***	0.000	-10.35 ***	0.000	-16.27***	0.000	-10.49***	0.000

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10 % probability level.

Table 3.19: Relative risk ratios of the multinomial logit climate change adaptation model

Adaptive Strategies	Shifting growing season		Introduction of Climate tolerant varieties		Innovative farming practices		Short duration crop		Farming of non-rice crops		Excavation of pond/canal and drainage improvement		Agro-forestry and homestead gardening	
Explanatory Variables	RRR	P level	RRR	P level	RRR	P level	RRR	P level	RRR	P level	RRR	P level	RRR	P level
Age	0.999	0.980	0.974	0.605	0.980	0.733	0.986	0.802	0.976	0.649	1.052	0.421	0.960	0.465
Experience	1.023	0.614	1.041	0.388	1.051	0.336	1.035	0.489	1.053	0.283	1.030	0.584	1.083	0.115
Household size	1.967**	0.024	2.223***	0.008	2.065**	0.022	2.257***	0.008	1.952**	0.029	2.392***	0.008	2.074**	0.018
Household income	1.000	0.355	1.000	0.286	1.000	0.853	1.000	0.270	1.000	0.408	1.000	0.266	1.000	0.632
Livestock ownership	3.561*	0.079	3.975*	0.062	2.580	0.244	5.297**	0.046	3.621*	0.093	1.200	0.857	4.123*	0.072
Tenure status	5.101**	0.048	4.312*	0.082	15.294***	0.006	4.562*	0.108	3.213	0.179	11.807*	0.084	6.775**	0.033
Farm size	1.012*	0.088	1.012*	0.088	1.017**	0.018	1.013*	0.080	1.014*	0.057	1.010	0.276	1.012*	0.100
Agriculture extension	1.529	0.583	1.596	0.555	1.817	0.508	1.136	0.886	0.998	0.998	1.020	0.987	1.976	0.428
Farmer to farmer extension	0.606	0.529	0.786	0.767	1.743	0.561	1.047	0.960	1.601	0.586	1.077	0.948	0.478	0.384
Climate information	4.492*	0.068	7.698**	0.020	2.853	0.287	6.542*	0.087	10.480**	0.017	0.715	0.788	6.837**	0.051
Credit access	5.754**	0.041	6.306**	0.033	10.230**	0.013	6.023**	0.051	6.878**	0.030	6.677*	0.078	5.975**	0.048
Market Distance	0.608*	0.062	0.563**	0.038	0.532**	0.050	0.594*	0.092	0.575*	0.056	0.710	0.369	0.751	0.316
Education	1.348**	0.022	1.288*	0.056	1.250	0.115	1.371**	0.024	1.307**	0.048	1.656***	0.003	1.354**	0.028
Nonfarm income	1.000*	0.078	1.000*	0.081	1.000	0.585	1.000*	0.091	1.000*	0.085	1.000**	0.047	1.000	0.219
Constant	0.0001 ***	0.000	0.00005 ***	0.000	0.00001 ***	0.000	3.41e-06 ***	0.000	.000032 ***	0.000	8.63e-08 ***	0.000	0.000028 ***	0.000

***Significant at 1% probability level, ** Significant at 5% probability level,* Significant at 10 % probability level.

Chapter Four: Discussion

4.1 Climate variability and change in the study area:

The descriptive statistics such as mean, standard deviation, coefficient of variation, skewness, kurtosis, minimum and maximum were estimated for five major annual climate variables (maximum temperature, minimum temperature, rainfall, relative humidity and sunshine duration) to get an extensive idea about the general properties of the variables under study for the total period (Table 3.1). It was revealed that the study area experienced highest variability in rainfall (14.99%) and sunshine duration (5.89%). The descriptive statistics of major annual climate variables were also calculated for the last three decades (1985-1994, 1995-2004 and 2005-2014) with particular focus on mean, standard deviation and CV as these statistics provide a detailed impression about climate variability and change (Table 3.2). It was observed that mean maximum and minimum temperature were increased consistently while rainfall and its variability were decreased substantially over the decades. The 5-yearly moving average method also supports the strong climate variability in studied area. In addition, various spell of fluctuations in climate variables can be easily recognized from Figures 3.1 to 3.10, giving evidence of the climate variability. The agricultural production of the area is greatly influenced by the variations and change that observed in climate variables.

However, the aforesaid description only reflects a partial view of change in climate variables in the study area over the period. So, additional examination was undertaken to detect the potential trends in annual climate variables by applying linear trend model with time (year) as an independent variable (Table 3.3 and Figure 3.11 to 3.16). The results revealed that mean temperature, maximum temperature, minimum temperature and sunshine duration showed significant trend whereas rainfall and relative humidity exhibited no significant trend over the periods. Among the significant climate variables, upward trend was noticed in mean temperature, maximum temperature and minimum temperature while a downward trend identified in sunshine duration. Moreover, the highest trend (0.0219 ^{0}C/year) was observed in annual maximum temperature. According to the model results, positive trends of 1.94, 2.19 and 1.67 ^{0}C per century were observed in mean temperature, maximum temperature and minimum temperature respectively while a negative trend of 0.172 hours per decade was noticed in sunshine. These findings are consistent with some studies conducted in Bangladesh (CDMP, 2012; Sarker et al., 2012; Ahmed, 2006; Agarwala et al., 2003; Mondal and Wasimi, 2004). An increasing trend of 2.4 ^{0}C per century for recent annual mean temperature and a decreasing trend of 5.3 % per decade for sunshine was reported by CDMP (2012). In the present study, the significant downward trend in rainfall is observed in case of 80% confidence level, whereas such trend is not significant at 95% level. This finding conflicts with Shahid (2010) and CDMP (2012). The former study indicates an increasing trend of 5.5 mm/year (5% significance level) in annual rainfall of Bangladesh, while no significant trend for country's annual rainfall in later study. This could be due to the regional variability and change in climate. The above trends and scenarios with variability in most climate parameters provided us a clear evidence of changing climate in Greater Noakhali Region over the last three decades. Further, the following paragraph gives an idea of climate variability with crop growing seasons in Bangladesh as it has a direct relationship with crop production.

The descriptive statistics ascertained that the highest growing season climate variability (52.93%) was observed in rainfall, particularly in Rabi season as indicated by coefficient of variation (CV). Trend graphs (Figure 3.17 to 3.21) revealed that climate variables varied not only among growing seasons but also within growing seasons in the study area. The notable trend was distinguished in maximum temperature, rainfall and sunshine duration, of which maximum temperature exhibited an upward trend while rainfall and sunshine expressed a downward trend. In all three seasons, rainfall was noticed to demonstrate a downward trend with extreme fluctuations especially in Kharif-1 and Kharif-2 seasons affecting crop yields substantially.

4.2 Crop yield-climate relationship

Boro yield model: Overall, Boro rice yield model was statistically significant at 1% level implying that the model has a strong explanatory power. Basic assumptions of multiple regression were fulfilled in the model as demonstrated by regression diagnostics (Table 3.6). The R^2 value identified that 52.2% variation in Boro yield was impacted by climate variability and change. The significant regression coefficients interpreted that 1^0C increase in minimum temperature would lead to an increase of 4.2% in Boro yield; 1 mm increase in rainfall would lead to an increase of 0.028% in Boro yield and 1% increase in relative humidity would lead to a decrease of 1.4% in Boro yield. It was also found that maximum temperature affected the Boro rice yield while minimum temperature and rainfall significantly benefitted the Boro rice yield, although the coefficient of maximum temperature was not significant. Insignificant regression coefficients can be used to determine the true effect of climate variables on the yield of major food crops for the present study (Nicholls, 1997). The above findings are consistent with the previous studies (Sarker, 2012; Amin et al., 2015) indicating the same pattern of effect of maximum temperature, minimum temperature and rainfall on Boro yield for the entire Bangladesh. On the other hand, relative humidity significantly and negatively influenced the Boro rice yield. But a positive relationship between relative humidity and Boro rice yield at the national level was found by Amin et al. (2015). This might be referred to the regional variability of climate that affected Boro yield differently. In addition, sunshine duration expressed insignificant but positive influence on the yield of Boro rice (Amin et al., 2015).

Aman yield model: The yield model was statistically significant at 2% level demonstrating the effect of overall climate variables on Aman yield, although most of the regression coefficients were not significant in the model. Basic regression assumptions were also met in the model as indicated by regression diagnostics (Table 3.7). The R^2 value explained that 42.1% of Aman yield variation was influenced by climate variability. The significant coefficient explained that 1 hour increase in sunshine would lead to an increase of 0.29% in Aman yield. It was also found that maximum temperature expressed positive and minimum temperature expressed negative influence on Aman rice yield, although coefficients were not significant. These findings have got similarities with

Sarker (2012) where the similar effect of maximum and minimum temperature on Aman yield was found all over Bangladesh. It was also revealed that rainfall affected the Aman yield in the study area which is similar with the result of Amin et al. (2015). But Sarker (2012) studied a significant positive impact of rainfall on Aman yield. Though both studies were conducted for whole Bangladesh, the difference in their result might be due to the difference in the selection of growing periods and data arrangement. On the other hand, relative humidity exhibited positive influence on Aman yield which is also consistent with the finding of Amin et al. (2015). Moreover, it was found that sunshine duration statistically significantly and positively influenced the Aman yield. But Amin et al. (2015) explored a negative effect of sunshine on Aman yield, although regression coefficient was not significant. The difference in the effect of sunshine on Aman yield might be contributed to the regional variability of climate.

Aus yield model: The yield model for Aus rice was highly significant at 1% level indicating its strong explanatory power. Basic assumptions of multiple regression were satisfied in the model as denoted by regression diagnostics (Table 3.8). The R^2 value indicated that 53.8% variation in Aus yield was influenced by climate variation. The significant regression coefficients elucidated that 1^0C increase in maximum temperature would lead to an increase of 15.2% in Aus yield and 1% increase in relative humidity would lead to an increase of 3% in Aus yield. It was also found that maximum temperature contributed positively to the yield of Aus rice which was highly significant at 1% level. This result is also similar with the past studies (Sarker, 2012; Amin et al., 2015). In case of minimum temperature, a positive influence on Aus yield was identified which is consistent with the finding of Amin et al. (2015). Moreover, rainfall contributed positively yet insignificantly to the Aus rice yield which shows the similar result with Sarker (2012). However, Amin et al. (2015) found a negative but insignificant effect of rainfall on Aus yield. The dissimilarities in rainfall effect attributed to the regional climate variability. Further, relative humidity showed significant positive impact on Aus yield which is also consistent with the study of Amin et al. (2015). On the other hand, sunshine negatively influenced the yield of Aus rice.

Pulse yield model: The pulse yield model was statistically significant at 5% level with the inclusion of three climate variables (rainfall, relative humidity and sunshine). Because the model was insignificant and invalid with the inclusion of all five climate variables. Basic regression assumptions were met in the model as revealed from the regression diagnostics (Table 3.9). The R^2 value demonstrated that 25.8% of the pulse yield variation could be explained by climate variability and change. The significant coefficients interpreted that 1% increase in relative humidity would lead to an increase of 13.6 kg/acre in pulse yield and 1 hour increase in sunshine would lead to an increase of 49.2 kg/acre in pulse yield. It was found that rainfall influenced pulse production negatively in the study area, although the coefficient was not significant. The result is consistent with the study of Hamjah (2014) who investigated the negative effect of dry season rainfall on the pulse production, such as mung bean, gram, grasspea and lentil at the national level of Bangladesh. In addition, relative humidity exhibited positive effect on Pulse yield which was significant at 3% level. This result has got similarity with the findings of Hamjah (2014) for grasspea, a kind of pulse. On the other hand, sunshine hours contributed positively to the pulse yield which was very significant at 1% level. But Hamjah (2014) found a significant negative impact of dry season sunshine on the yield of pulses such as mung bean and lentil. This disparity in sunshine effect on crop production can be attributed to the regional variability of climate.

Groundnut yield model: The crop yield model for groundnut was statistically significant at 8% level with the introduction of three climate variables (minimum temperature, rainfall and sunshine). Because like pulse yield model, it would also become insignificant and invalid with the incorporation of all five climate variables. Basic assumptions of multiple regression were also satisfied in the model according to regression diagnostics (Table 3.10). The R^2 value indicated that 23.1% variation in groundnut yield was regulated by climate variability and change. The significant coefficient elucidated that 1 hour increase in sunshine duration would lead to a decrease of 7.1% in groundnut yield. It was observed that minimum temperature benefitted the groundnut yield while rainfall affected the yield of groundnut, although coefficients were not significant at 5% level but it would become significant at 20% level (80% confidence interval). The similar positive effect of temperature on groundnut (peanut) was observed by Chalise and Ghimire (2013) who investigated the effect of temperature and precipitation on peanut's yield in the state of Georgia, USA using historical time series data. But Tunde et al. (2011) found a negative impact of temperature on groundnut yield in Nigeria at a regional level study. Moreover, the similar negative effect of rainfall on groundnut yield was identified by the previous studies (Tunde et al., 2011; Chalise and Ghimire, 2013). On the other hand, sunshine expressed negative influence on groundnut yield which was significant at 2% level. Based on the above results, it can be deduced that the effect of climate variables varies not only among crops but also across regions.

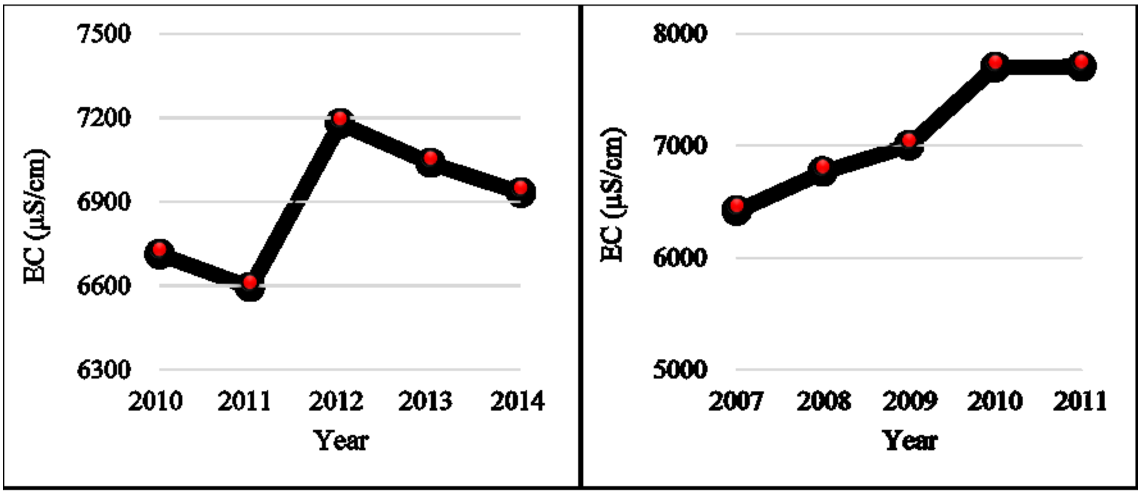
Examining the R^2 value of five crop model, it is inferred that the yield of Aman (42.1%), Boro (52.2%) and Aus rice (53.8%) were highly influenced by climate variability and change which are ranked as the 1st, 2nd and 3rd major food crops in the study area. An interesting finding revealed from the present study is that the climatic influence on three rice crops was much higher than other two major crops. Therefore, it is suggested that any program dealing with reducing the adverse impact of climate change on major agricultural crops should give first preference to the crops like Aus, Aman and Boro rice, which are being affected at a greater extent in compared to other major crops. Moreover, rice is the staple food crop not only in Bangladesh but also in the region in view of both cropping area (Table 3.12) and production (Appendix-5).

Another significant finding identified from the crop-wise investigation is that rainfall expressed positive influence on Boro rice yield. In general, Boro rice is cultivated under irrigated conditions in the study area. This supports the fact that irrigation facilities should be increased and expanded throughout the region to increase overall Boro production as we already know that irrigation coverage is comparatively lower in Greater Noakhali region than other parts of the country. According to the Boro yield model, maximum temperature contributed negatively to the Boro rice production. Considering the adverse effect of temperature on Boro rice production, the policymakers should take necessary steps for the development of temperature tolerant Boro rice varieties in the region. In case of Aman rice, it was found that minimum temperature exhibited negative influence on Aman yield. Moreover, rainfall influenced the Aman yield negatively. As Aman rice is grown completely under rainfed condition, seasonal intense and erratic rainfall pattern might affect its production severely. The water logging problem in the study area might also contributed to this effect. Regarding the negative effect of temperature and rainfall on Aman rice, expansion of temperature and flood tolerant varies are recommended for Aman in the region. In view of Aus rice, both temperature and rainfall favored the Aus yield. On the other hand, it was found that rainfall demonstrated a negative impact on the yield of both pulse and groundnut which justified the cultivation of these two crops in the dry (Rabi) season.

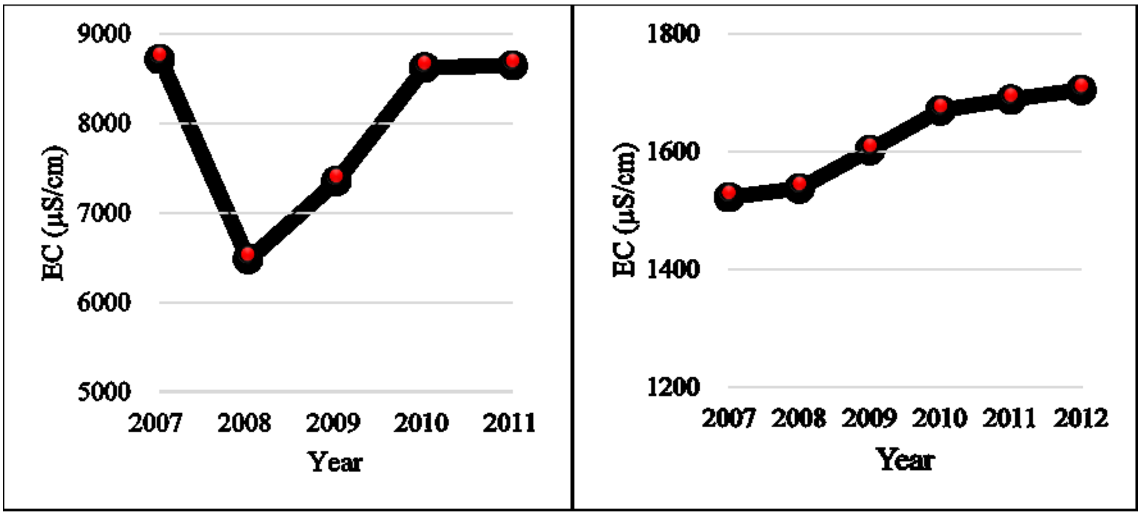
4.3 Causes of cropping pattern change

The change in cropping pattern is mainly responsible for climate variability (75%) as revealed from the questionnaire survey and FGDs (Figure 3.35). Since the response from farmers' survey is not sufficient to assert that climate change is the principal cause of cropping pattern change. As a result, further verification was performed using some empirical data and reviewing some relevant literature.

From the water salinity trend of four river stations in Greater Noakhali Region, upward trends are observed for Noakhali canal at Noakhali station and Rahmatkhali canal at Lakshmipur station, whereas irregular patterns for the remaining stations (Figure 4.1). Overall, an increasing trend in water salinity was detected in the region.



(a) Companyganj station (b) Noakhali station



(c) Bhawaniganj station (d) Lakshmipur station

Figure 4.1 (a, b, c, d): Water salinity trend of 4 river stations in study area (BWDB, 2016).

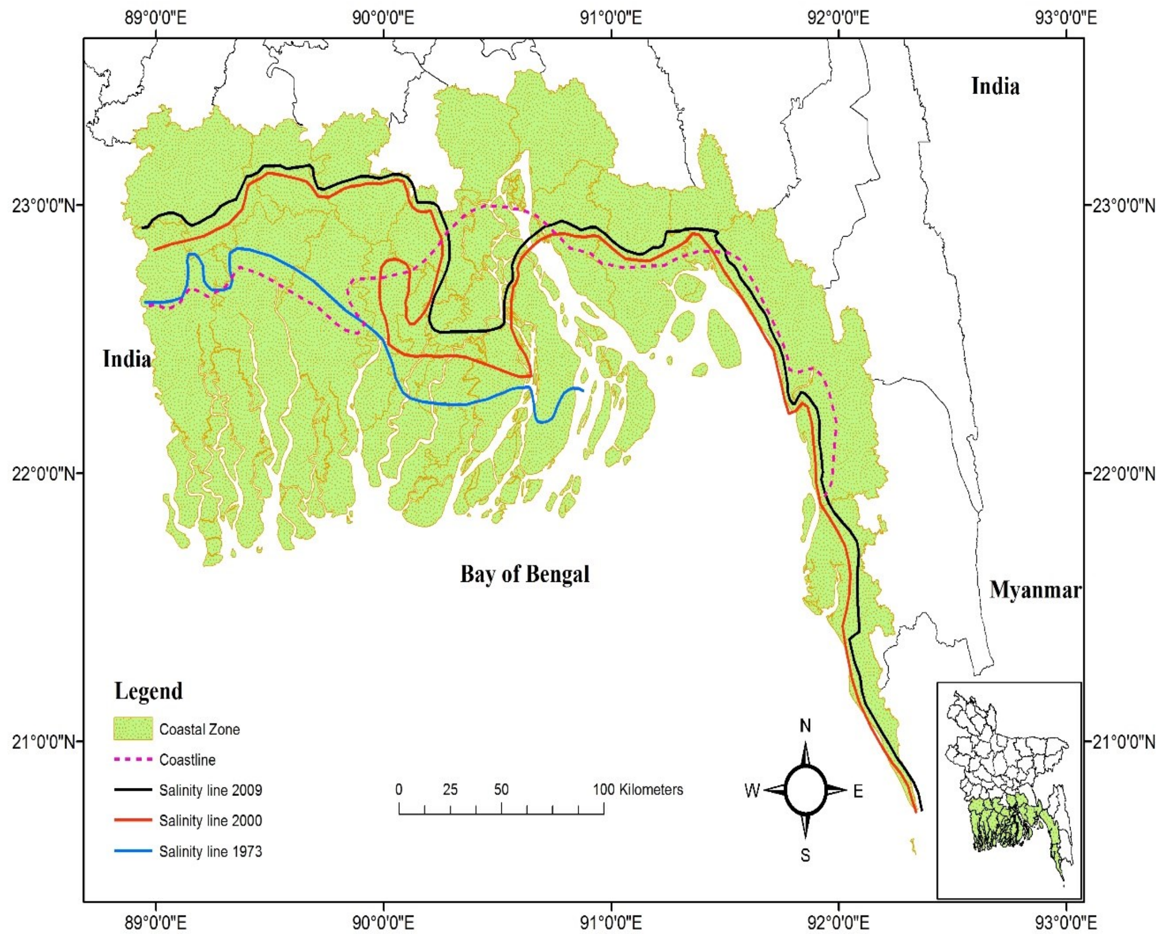


Figure 4.2: Bangladesh soil salinity map showing the soil salinity boundary over three time periods (Based on SRDI, 2010).

Analyzing the soil salinity map of Bangladesh (Figure 4.2), the notable change in salinity affected area is observed among three periods of time (1973, 2000 and 2009). The figure also shows that the salinity coverage remarkably increased from 1973 to 2000, whereas slightly increased in the following period till 2009.

Investigating historical major floods and its inundation area (percentage) between 1954 and 2008, it was disclosed that five severe floods occurred between 1987 and 2008 (the present study period) which inundated more than one-third area of the entire country (Figure 4.3) and caused a huge loss in crop production (Figure 4.4). Among five historical severe floods, Bangladesh as well as the study area had been affected by two drastic floods in 1988 and 1998 which submerged approximately two-third area of the country and incurred a crop damage of over of 3 million tons. These might have adversely affected the cropping pattern in the study area.

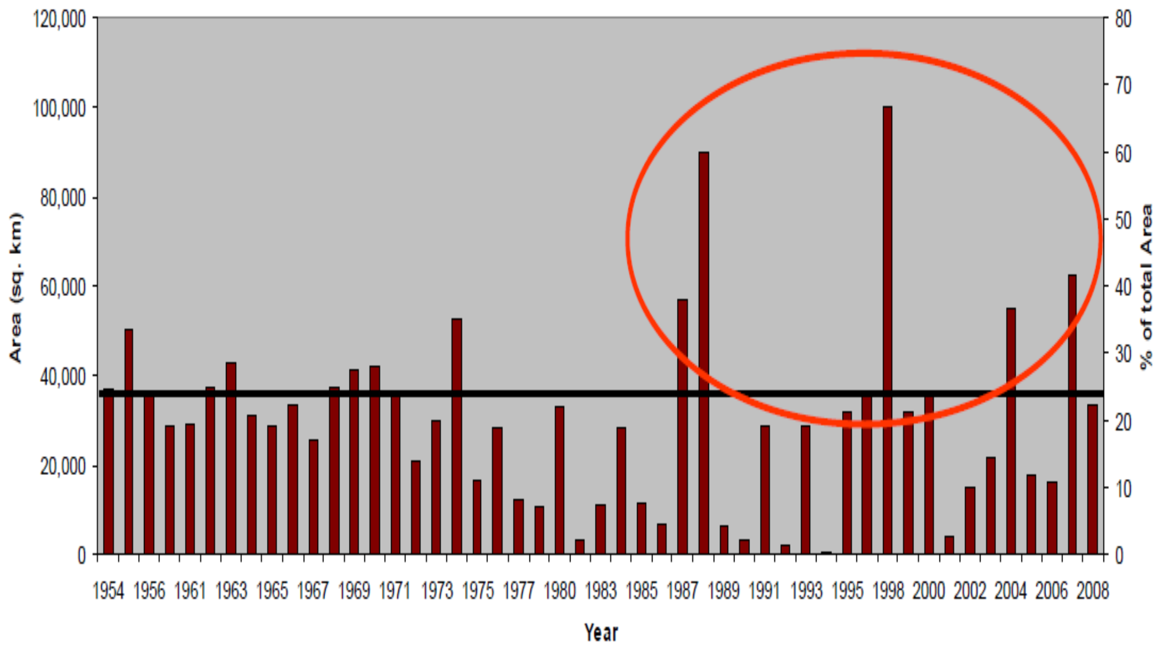


Figure 4.3: Coverage of Inundation in Major Floods of Bangladesh, 1954-2008 (Ali, 2010).

Around 59 major cyclones from 1797 to 1991 Period hit Bangladesh coast (Khan, 2013). Among them, Greater Noakhali coast experienced 18 major cyclones. From the behavior of above hydro-meteorological (climatic) factors, it can be deduced that the region severely affected by climate change during the study period.

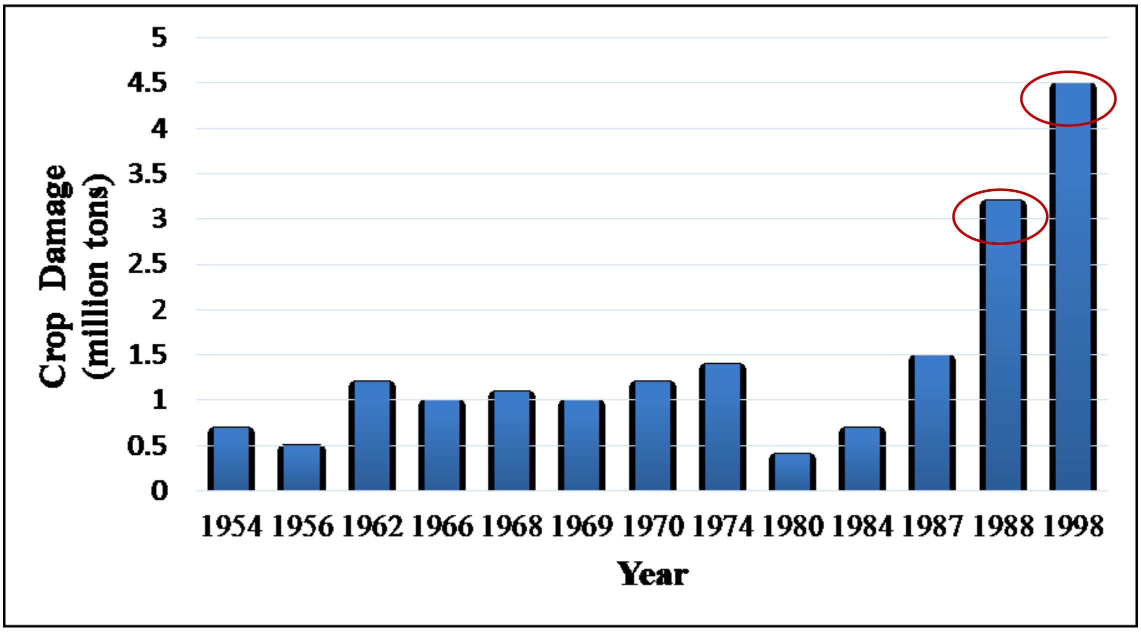


Figure 4.4: Crop Damage in Major Floods of Bangladesh, 1954-1998 (Dewan et al., 2003).

Although Bangladesh mainly consists of 30 agro-ecological zones (AEZ), Quddus (2009) arranged 30 AEZs into 12 categories based on the homogenous characteristics of AEZs. Greater Noakhali Region is categorized into one of these AEZs named LMREF. In his study, the agricultural development of 12 agro-ecological zones had been compared between two time periods (1980-83 and 2000-04). It is found that population density and literacy rate, particularly rural literacy, increased significantly by 26% and 22% respectively during the study period. Though the ratio of agricultural workers to population increased by 10.5%, per capita food grain production decreased by 1.5% per year in the region, which is a matter concern in compared to other AEZs' food production. Though total cropped area and cropping intensity were increased by 14.3% and 42% respectively, the net cropped area in the AEZ was reduced by 11%, one of the highest reduction rate in the country.

In terms of both area under HYV and percentage cropped area under HYV, the lowest increment was also observed in the region during the study period in compared to other AEZs according to the study result (Quddus, 2009). The HYV cropped area increased only by 0.2 times while the percentage cropped area under HYV was raised by 11.6% (Table 4.1). In view of production, the growth rate of planting HYV crop was also slower in the region (LMREF). The lowest irrigation coverage was further noticed in the region in comparison with other AEZs of the country which is only 13.5% in 2000-03.

Table 4.1: Growth of HYV crop in LMREF region

Region	Area under HYV ('000 ha)			Area under HYV as a % of total cropped area		
	1980-1983	2000-2003	Increase in 20 years (times)	1980-1983	2000-2003	Increase in 20 years (times)
HPTF	351	1429	3.0	17.6	67.5	49.9
KFAB	249	1397	4.6	18.7	85.8	67.1
BJF	602	1324	1.2	27.7	62.1	34.4
HGRF	273	1123	3.1	16.4	59.6	43.2
LGRF	150	235	0.6	19.7	28.3	8.6
GTF	191	496	1.6	11.9	26.3	14.4
SBSKF	140	408	1.9	13.9	41.4	27.5
MMRF	327	564	0.7	36.7	60.5	23.8
LMREF	200	238	0.2	29.6	41.2	11.6
CCPSI	286	357	0.2	63.6	72.3	8.7
EH	40	52	0.3	40.3	37.1	3.7
DHAKA	179	346	0.9	24.2	48.5	24.3

Source: Quddus, 2009.

It is very obvious from the above discussions that agricultural development is slower and unbalanced in Greater Noakhali Region (LMREF) than other agro-ecological zones of Bangladesh during the study period (Quddus, 2009). Hence, it can be said that agricultural development is not the main reason of changing cropping pattern. Therefore, it can be inferred that climate change is mainly accountable for cropping pattern change in the study area though the contributions of some non-climatic factors are not negligible.

Causes of cropping pattern change vary from country to country and area to area. Both climatic and non-climatic factors determine the cropping pattern of a specific region. Though globalization trend, technological improvement, consumption pressure, market force, etc. significantly contributed to the change in cropping pattern in recent times, the role of climatic factors in cropping pattern change cannot be ignored. Because in most parts of the world, agriculture is still fully dependent on nature and its surrounding environment particularly on temperature, rainfall and sunshine. Some studies recognized climatic factors as major causes of cropping pattern change (Ahmed et al., 2016; De and Bodosa, 2014; Gunarathna, 2004) while other studies identified non-climatic factors as significant causes of cropping pattern change (Ratheesh, 2014). The only significant study at the national level of Bangladesh was carried out by Mahmood (1998) who found that thermal climate variation had significant impact on the transplanting and harvesting dates of Boro rice and the resultant potential changes in cropping pattern using a crop-climate model. Thus, it can be inferred that climatic factors are mainly responsible for cropping pattern change in the study area. To get a more concrete and robust finding, a more detailed study considering more climatic and non-climatic factors with longer period data are required in this context.

4.4 Farmers' adaptation strategies and its significant determinants

It is very useful to ascertain the farmers' adaptation strategies in order to get a comprehensive impression about an agricultural system's adaptive capacity (Reid et al., 2007). In the study area, farmers have always made adaptive changes to their farming system based on the weather and respond by changing cropping patterns and management practices. Farm level analyses have demonstrated that sizeable reductions in adverse impacts from climate change are possible when adaptation is fully implemented (Mendelsohn and Dinar, 1999).

The questionnaire survey affirmed that 90% (n=400) farmers adopted adaptation methods while 10% farmers undertaken no adaptation measures in the study area (Figure 3.39a). The most common adaptation choice practiced by the farmers was shifting growing season (27%) presumably due to its ease of operation and no additional cost requirement (Figure 3.39b).

Based on their perception of climate, farmers in the study areas are often adapted to plant their crops few days earlier or later than the prescribed growing season in order to avoid extreme climatic events such as high and low temperature stress, excessive rainfall (flood), no rainfall (drought), etc. Farmers also adopted different climate tolerant crop varieties in order to reduce potential negative effect of extreme climates. The major climate tolerant, non-rice and short duration crops cultivated in the study area are shown in Table 4.2.

Table 4.2: Major climate tolerant, non-rice and short duration crops cultivated in the study area

Type		**Crop Variety**
Climate tolerant crop variety	Drought tolerant	Rice: BRRI-42, 43, 56, 57
	Saline tolerant	Rice: BRRI-47 and BINA-7, 8, 10 (Rabi) Rice: BR- 23, 61 and BRRI- 40, 41, 53, 54, 55 (Kharif-2) Other crops: Green chili, sweet potato, cowpea, etc.
	Flood tolerant	Rice: BRRI-51, 52 and BINA-11, 12
Non-rice crop		Groundnut, various kinds of pulse, soybean, green chili, vegetables, etc.
Short duration crop		Rice: BRRI- 33, 39,56,57,62 Other crops: Various kinds of pulse such as lentil, mungbean, gram, grasspea, cowpea, etc.

In addition, farmers practices agroforestry and homestead gardening as one of the major adaptation options. The benefits of agroforestry and homestead gardening are mainly related to the conservation of soil, nutrients and biodiversity. Homestead gardening meets the basic need of the farmer and high species diversity help to reduce the environmental degradation. Coconut, betel nut, carambola (starfruit), mango, jackfruit, guava, sugar palm, papaya, tamarind, blackberry, etc. are grown as fruit species whereas bottle gourd, pumpkin, red amaranth, stem amaranth, bean, spinach, radish, brinjal, bitter gourd, tomato, etc. are planted as vegetables in the study area besides some timber species in the homestead setting. Agroforestry practices in the coastal region not only serve as a source of fruit, timber, fuel wood and vegetable, but also work as green bio-shield to secure the homesteads against all climatic hazards initiated from the Bay of Bengal (Islam et al., 2015). It was also found that mulching, one of the innovative farming practices, are practiced frequently by famers in the study area in order to minimize the climate stress on crops and plants. Different type of materials such as organic residues (grass clipping, straw, hay, and leaves), compost, plastic sheet, etc. are used as mulches which are normally applied to the soil surface, around trees and flower beds in order to retain soil moisture, regulate soil temperature and control weed growth. Excavation of pond, canal and drainage improvement is executed as an adaptation option with a view to reduce the water-logging problem. It helps the farmers during drought period to fulfill their water (irrigation) requirement for cultivation. Moreover, some farmers earn extra money by using the ponds and canals for fish culture which improve their livelihood status and ultimately strength adaptation to climate change.

Factors such as accessibility and effectiveness of climatic information, the institutional setting and the socio-economic conditions of households determine farmers' capacity to adapt to climate change (Ziervogel et al., 2006; Agarwal, 2008). Some barriers or difficulties have been facing by the farmers in accomplishing adaptations in the study area (Figure 3.40b). The major obstructions and challenges encountered by the farmers include lack of knowledge concerning appropriate adaptation measure, inadequate irrigation facilities, insufficient credit facilities, shortage of labor, dissemination of climate information on time, etc. Therefore, the expansion of agricultural education, strengthening of agriculture extension regarding appropriate adaptive technology, spreading irrigation facilities, ensuring credit facilities in the rural areas and available information on change in potential climate variables are essential to ensure the effective adaptation mean.

Significant determinants of farmers' adaptation choices: evidence from MNL model

The results of the MNL model disclosed that the significant determinants that affect farmers' adaptation choices in the study area incorporate household size, livestock ownership, tenure status (land ownership), farm size, information on climate and access to credit, distance to market, education and nonfarm income. The factors or determinants that found insignificant under MNL model include age, experience, household income, agriculture extension and farmer to farmer extension (Table 3.19). Following Bryan et al.

(2009) and Sarker (2012), only the statistically significant variables affecting adaptation choices are discussed here.

Household size: In general, household size increases the likelihood of adopting all adaptation choices practiced in the study area. More specifically, it increases the probability of implementing shifting growing season by 1.97 times, using climate tolerant varieties by 2.22 times, innovative farming practices by 2.07 times, using short duration crop by 2.26 times, farming of non-rice crops by 1.95 times, the excavation of pond, canal and drainage improvement by 2.39 times and agro-forestry and homestead gardening by 2.07 times in compared to no adaptation. It was hypothesized that the larger the size of the household, the better the probability of adapting to climate change. This is consistent with the finding of Yirga (2007) that households with large families might be pushed to transfer part of the labor force to non-farm income activities in an attempt to earn extra income in order to abate the consumption pressure imposed by a large family. The result is also consistent with other finding made by Croppenstedt et al. (2003) that households with a higher pool of labor are more likely to implement agricultural technology and utilize it more effectively as they have no labor constraints at peak times.

Livestock ownership: Livestock ownership significantly increases the probability of undertaking most of the adaptation methods except innovative farming practices and excavation of pond, canal and drainage improvement. More definitely, it increases the likelihood of adopting shifting growing season by 3.56 times, introduction of climate tolerant varieties by 3.98 times, planting short duration crop by 5.3 times, farming of non-rice crops by 3.62 times, and agro-forestry and homestead gardening by 4.12 times in compared to no adaptation. The result is similar with the finding of Yirga (2007) that livestock plays a very significant role by serving as a store of value and by providing traction (particularly oxen) and manure necessary for soil fertility improvement.

Tenure status: Tenure status (i.e., land ownership) is generally believed to motivate the adoption of new technologies. Tenure status significantly increases the probability of undertaking most of the adaptation options except farming of non-rice crops as compared to no adaptation. In particular, tenure status increases the probability of adopting innovative farming practices by 15.2 times, the excavation of pond, canal and drainage improvement by 11.8 times, agroforestry and homestead gardening by 6.8 times, shifting growing season by 5.1 times, introduction of climate tolerant varieties by 4.3 times and so on. The similar positive effect of tenure status on adaptation options was found in some other studies (Bryan et al., 2009; Gbetibouo, 2009; Hisali et al., 2011).

Farm size: Farm size significantly increases the chances of adopting all adaptation strategies in our study except the excavation of pond, canal and drainage improvement. This is due to the fact that big farmers are generally provided with more capital and other farm resources and are more likely to adapt. The result is in line with other studies (Bryan et al., 2009; Gbetibouo, 2009).

Access to information on climate: Information on climate has a positive and significant impact on most of the adaptation strategies except innovative farming practices and the excavation of pond, canal and drainage improvement. In particular, information on climate change increases the likelihood of adopting farming of non-rice crop by 10.5 times, introduction of climate tolerant varieties by 7.7 times, agroforestry and homestead gardening 6.8 times, short duration crop by 6.5 times and so on. This result is also similar with other studies (Yirga, 2007, Maddison, 2006; Nhemachena and Hassan, 2007) that access to information through extension increases the likelihood of adapting to climate change.

Access to credit: Access to credit significantly increases the likelihood of adopting all seven adaptation strategies in the present study. This is due to the fact that availability of credit soothes the cash constraints and allows farmers to buy agricultural inputs such as fertilizer, improved crop varieties and irrigation facilities. In particular, access to credit increases the probability of executing shifting growing season by 5.75 times, planting climate tolerant varieties by 6.31 times, innovative farming practices by 10.23 times, using short duration crop by 6.02 times, farming non-rice crops by 6.88 times, excavation of pond, canal and drainage improvement by 6.68 times and agro-forestry and homestead gardening by 5.98 times in compared to no adaptation. The positive impact of credit on adaptation is consistent with other studies (Deressa et al., 2009; Hisali et al., 2011).

Distance to market: In the present study, market distance significantly decreases the chances of adoption of most of the adaptation means. More precisely, it decreases the likelihood of adoption of shifting growing season by 0.61 times, introduction of climate tolerant varieties by 0.56 times, innovative farming practices by 0.53 times, planting short duration crop by 0.59 times and farming of non-rice crops by 0.58 times. The result is consistent with the hypothesis that as distance to output and input markets increases, adaptation to climate change decreases. As it is well known that market acts as a place of information exchange and adopting new technology and thereby, strength adaptation (Maddison 2006).

Education: Higher degree of education is normally related with access to information on advanced technologies and higher productivity (Norris and Batie, 1987). Evidence from various sources confirms a positive association between the education level of the household head and the acquisition of improved agricultural technologies (Lin, 1991) and adaptation to climate change (Maddison, 2006; Deressa et al., 2009).Years of education of household head significantly increases the probability of adopting all adaptation options excluding innovative farming practices. The values of RRR denote that the education of the household head significantly increases the likelihood of implementing shifting growing season by 1.35 times, introduction of climate tolerant varieties by 1.29 times, planting short duration crop by 1.37 times, farming of non-rice crops by 1.31 times, the excavation of pond, canal and drainage improvement by 1.66 times and agro-forestry and homestead gardening by 1.35 times in compared to no adaptation.

Non-Farm income: Farm and nonfarm income are the indicators of financial capacity which reinforces the adoption of agricultural technology (Knowler and Bradshaw, 2007). Nonfarm income is a significant determinant for all adaptive choices excluding innovative farming practices and agroforestry and homestead gardening. But it could not enhance the probability of adaptation choices as revealed from the RRR value. The significant effect of nonfarm income is in line with the findings of Deressa et al. (2009).

Other determinants: Among insignificant variables, experience and agriculture extension increases the likelihood of using different adaptation options while age slightly reduces the chance of using most of the adaptation options. On the other hand, household income could not increase the likelihood of implementing adaptation choices while farmer to farmer extension increases the chance of adoption for some adaptation choices and also reduces the chance of adoption for the remaining choices.

The most significant determinants that have been revealed from the model involve tenure status, information on climate, access to credit and livestock ownership as the RRR values of these variables are predominantly higher for most of the adaptation categories (Table 3.19). It is worth mentioning that these significant determinants are likely to increase farmers' adaptive capacity. Therefore, government policy should focus boosting these significant determinants to strengthen farmers' adaptation strategies and hence to lessen vulnerability.

Chapter Five: Conclusions and Recommendations

5.1 Conclusions and Recommendations

Climate change-induced agricultural vulnerability has been clearly evidenced in Bangladesh and widely recognized over the country as well as throughout the globe. In considering this issue, this study was carried out with a 30-year data set of the agro-climatic parameters from 1985 to 2014 in south-eastern coastal region of the country to investigate the impact of climate change on crop agriculture with particular attention to the determinants of adaptation choices in a regional scale. Descriptive statistics and linear model for analyzing trend in climate variables, OLS regression model with basic regression assumptions and non-climatic trend removal technique for observing the relationship between major crop yields and climate factors, and MNL model for assessing the significant determinants of the adaptation choices were employed in this study. The results disclosed the evidence of changing climate over the last three decades in the south-eastern coastal region of Bangladesh. The multiple regression models unveiled that climate variables have considerable effects on crop yields but the effects vary among different crops. Pronounced negative impacts of climate variables on major crops' yield were observed besides positive effects. Most importantly, maximum temperature and minimum temperature negatively influenced the yield of Boro and Aman rice respectively. Rainfall significantly benefitted the yield of Boro rice while affected the yield of Aman rice, pulse and groundnut though insignificantly. Moreover, relative humidity and sunshine expressed significant negative influence on Boro rice and groundnut successively. An interesting finding revealed from five crop models that the yield of three rice crops, such as Aman (42.1%), Boro (52.2%) and Aus (53.8%), were highly influenced by climate variability and change than other major crops. The second main objective of the study was to find out the causes of cropping pattern change and identify the farmers' adaptation strategies and its significant determinants in the face of climate change using a farm level micro data of 400 farm households obtained from questionnaire survey. The results revealed that climatic factors were mainly responsible for cropping pattern change with some non-climatic influences. Farmers' perceptions on climate change was consistent with the trend of regional climate data. Main adaptation strategies practiced by the farmers in the study area incorporate the shifting growing season, introduction of climate tolerant varieties, farming of non-rice crops, agroforestry and homestead gardening, planting short duration crop, innovative farming practices and the excavation of pond, canal and drainage improvement. Farmers identified the major barriers to adaptation as lack of knowledge concerning appropriate adaptation measure, inadequate irrigation facilities, credit constraints, unavailability of information about potential climate change, etc. The most significant finding demonstrated from the Multinomial logit (MNL) model that specifies household size, livestock ownership, tenure status, farm size, information on climate, access to credit, distance to market, education and nonfarm income are statistically significant determinants of adaptation measures. It is noteworthy that these significant determinants are likely to enhance farmers' adaptive capacity.

This study finds some important necessitates that policy maker should be taken into consideration for more resilient crop agriculture in the study area. These are (i) development and implementation of drought tolerant varieties, particularly for Boro and Aman rice, (ii) promotion of flood tolerant varieties for Aman rice, (iii) extension of irrigation facilities more intensively particularly for Boro rice, and (iv) continuation of rice varieties like Aus, Aman and Boro as the first priority crops. (v) In case of strengthening adaption under stressed environmental conditions, government policy should target improving the significant determinants of adaptation choices. For instance, investment in education, supply of necessary agricultural inputs at reasonable prices that increases farm income, generating opportunities for off-farm income, establishment of more financial institutions at the remote area, affordable credit facilities for small scale farmers at a low interest rate, distribution of government owned fallow (khas) land to the landless and poor farmers, and raising awareness on climate change at rural level can be adopted as appropriate policy options in order to reduce the adverse impacts of climate change in the south-east coastal region of Bangladesh.

5.2 Limitation and Future Study

The study was conducted using 30 years' time series data due to the limitation of data availability. It considered only five major climate variables such as annual maximum and minimum temperature, rainfall, relative humidity and sunshine duration and five major crops, namely Aus, Aman and Boro rice, groundnut and pulse.

Therefore, future researches might be undertaken using longer period time series data. Future studies might incorporate more climate and environmental variables such as atmospheric CO^2 concentration, wind speed, atmospheric pressure, etc. It might also consider other food crops like wheat, maize and vegetables and cash crops like jute and sugarcane in order to get a more comprehensive scenario of climate change impact on crop agriculture. A comparative study between food and cash crops can be performed regarding this. Moreover, future studies should be conducted on other important agro-ecological zones of Bangladesh as it is assumed that different agro-ecological zones impacted by climate change differently.

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Appendices

Appendix 1: Annual time series data of five major climate variables of Greater Noakhali region

Year	Major Climate Variables				
	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Total Rainfall (mm)	Relative Humidity (%)	Sunshine Durations (hrs)
1985	30.00	21.16	2795.5	80.3	6.55
1986	30.32	21.25	2876.5	79.8	6.62
1987	30.28	21.54	3742.0	80.8	6.53
1988	30.41	21.84	3220.0	81.7	6.35
1989	30.18	21.33	2820.5	79.5	6.60
1990	29.71	21.69	3832.0	82.0	6.02
1991	29.75	21.37	3868.0	81.3	5.65
1992	29.93	21.62	1892.0	81.1	6.09
1993	29.73	21.21	3676.5	80.9	5.98
1994	30.34	21.41	2458.5	79.6	6.55
1995	30.37	21.80	3044.5	80.5	6.33
1996	30.55	21.87	2837.5	81.0	6.98
1997	30.12	21.33	2753.0	81.0	6.60
1998	30.26	22.10	3557.0	82.3	6.29
1999	30.63	21.99	3427.0	81.2	6.57
2000	30.18	21.60	3229.5	80.6	6.62
2001	30.50	21.70	2884.0	80.1	6.88
2002	30.46	21.65	2891.0	80.0	6.44
2003	30.33	21.70	2871.0	80.3	6.85
2004	30.02	21.66	2920.0	81.4	6.32
2005	30.67	22.07	2884.5	81.5	6.50
2006	30.87	22.11	2316.5	81.1	6.09
2007	30.17	21.55	3528.5	81.5	5.72
2008	30.27	21.73	2939.0	81.8	6.07
2009	30.95	22.05	2896.5	81.3	6.35
2010	30.71	22.35	2855.5	81.7	6.04
2011	30.34	21.52	3214.0	81.5	5.76
2012	30.40	21.66	2675.5	81.5	5.81
2013	30.58	21.65	2766.0	79.9	5.70
2014	30.93	21.83	2661.5	79.7	5.93

Appendix 2: Kharif-1 growing season time series data of five major climate variables of Greater Noakhali region

Year	Major Climate Variables				
	Maximum Temperature (^0C)	Minimum Temperature (^0C)	Total Rainfall (mm)	Relative Humidity (%)	Sunshine Durations (hrs)
1985	30.98	23.94	1535.0	83.43	5.38
1986	32.27	23.94	1157.5	79.42	6.36
1987	31.80	24.14	1565.5	82.37	6.15
1988	31.49	24.22	1535.5	82.83	5.78
1989	32.18	24.37	1373.0	80.06	5.95
1990	30.75	23.76	1933.0	83.44	5.46
1991	31.67	23.95	1715.0	81.64	5.02
1992	31.98	24.67	770.5	81.09	5.45
1993	30.76	23.44	1785.5	82.24	5.46
1994	31.60	24.57	1488.0	82.01	5.88
1995	32.45	24.61	1502.5	80.81	5.92
1996	32.28	24.77	1378.0	82.77	6.37
1997	31.53	23.59	1089.0	83.12	5.87
1998	31.51	24.01	1569.5	83.37	5.69
1999	32.09	24.49	1748.0	82.61	5.68
2000	32.12	24.03	1535.0	80.38	6.32
2001	32.26	24.36	1436.0	80.11	6.64
2002	31.63	23.51	1731.0	82.18	5.22
2003	31.95	24.35	1463.5	81.76	6.28
2004	31.88	24.79	1222.5	82.76	5.46
2005	32.17	24.30	1341.5	82.89	6.23
2006	32.64	24.48	1296.0	80.43	6.12
2007	32.43	23.94	1304.5	80.92	6.05
2008	31.99	24.31	1522.5	82.90	5.48
2009	32.76	24.65	1407.0	82.17	6.31
2010	32.62	25.43	1408.5	83.19	5.46
2011	31.99	24.10	1574.5	84.59	5.51
2012	32.61	24.64	1390.0	82.89	5.82
2013	32.50	24.76	1371.0	81.21	5.59
2014	33.80	24.95	1217.5	79.01	6.42

Appendix 3: Kharif-2 growing season time series data of five major climate variables of Greater Noakhali region

Year	Major Climate Variables				
	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Total Rainfall (mm)	Relative Humidity (%)	Sunshine Durations (hrs)
1985	31.13	25.08	1211.0	84.77	6.05
1986	30.43	24.80	1539.5	87.27	4.80
1987	30.88	25.10	2044.0	87.32	4.48
1988	31.36	25.22	1461.5	86.25	4.70
1989	31.18	25.54	1316.0	85.19	4.98
1990	30.79	25.26	1575.0	85.85	4.93
1991	30.85	24.95	1913.0	86.68	4.21
1992	31.21	25.27	961.5	85.05	4.80
1993	30.76	24.91	1732.0	86.28	4.28
1994	31.44	25.05	949.5	84.75	5.48
1995	31.52	25.56	1252.5	85.51	5.22
1996	31.53	25.39	1165.0	86.18	5.56
1997	31.51	25.24	1620.5	85.18	5.92
1998	31.73	25.93	1666.0	86.10	4.72
1999	31.08	25.31	1484.0	86.55	4.74
2000	31.36	25.45	1373.5	85.07	5.16
2001	31.74	25.63	1245.0	85.62	5.55
2002	31.97	25.60	1027.0	84.26	5.22
2003	31.67	25.77	1265.0	85.08	5.85
2004	30.74	25.23	1631.5	86.49	5.16
2005	31.89	25.73	1346.0	86.21	5.28
2006	31.95	25.56	995.5	85.28	5.54
2007	31.14	25.46	1925.0	87.74	3.61
2008	31.66	25.29	1131.0	86.03	5.28
2009	31.74	25.75	1420.5	86.56	4.85
2010	32.00	25.99	1379.0	86.04	5.17
2011	31.91	25.75	1612.5	86.23	5.07
2012	31.39	25.57	1222.5	87.34	4.38
2013	31.68	25.71	1293.0	86.25	4.52
2014	32.16	25.81	1409.0	85.45	4.94

Appendix 4: Rabi growing season time series data of five major climate variables of Greater Noakhali region

Year	Major Climate Variables				
	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Total Rainfall (mm)	Relative Humidity (%)	Sunshine Durations (hrs)
1985	28.78	17.64	159.0	77.35	7.44
1986	29.13	16.99	76.0	75.50	8.06
1987	28.83	17.57	204.5	77.13	8.14
1988	29.16	18.29	154.5	78.94	7.88
1989	29.02	17.71	164.5	76.82	8.14
1990	27.64	17.53	240.0	80.67	6.96
1991	28.66	18.56	307.5	78.55	7.11
1992	27.58	17.96	217.5	80.31	6.83
1993	28.47	17.43	181.5	77.80	7.42
1994	28.73	17.69	58.0	77.02	7.55
1995	28.94	16.99	59.5	75.56	7.53
1996	28.82	18.61	256.5	78.94	8.01
1997	28.91	17.93	302.0	78.76	7.72
1998	27.85	17.78	83.5	79.59	7.41
1999	29.94	19.06	257.0	77.99	8.43
2000	28.22	18.48	348.0	79.87	7.41
2001	28.98	17.41	183.5	76.49	8.33
2002	29.00	18.29	198.5	78.47	7.89
2003	28.42	17.78	158.5	76.47	7.69
2004	28.58	18.02	113.0	78.95	7.73
2005	29.01	18.46	86.0	78.05	7.70
2006	29.23	18.94	174.0	79.60	7.10
2007	28.11	17.44	99.0	79.48	6.05
2008	28.24	18.22	283.5	79.51	6.83
2009	29.11	18.52	227.5	80.26	7.03
2010	28.89	18.06	86.5	77.96	7.05
2011	28.99	18.08	57.0	76.88	7.40
2012	28.68	18.08	58.5	78.15	6.24
2013	28.76	17.25	29.0	76.12	7.08
2014	28.36	17.45	113.5	77.13	6.42

Appendix 5: Cropping area, production & yield data of historical major crop of Greater Noakhali Region: Aus, Aman & Boro rice

Year	Aus Rice			Aman Rice			Boro Rice		
	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)
1985	136228	198068	588.64	311103	635486	827.00	69743	205753	1194.40
1986	129745	188874	589.37	309140	632374	828.17	71399	209972	1190.62
1987	129108	168115	527.18	297025	606520	826.71	71925	207959	1170.58
1988	147247	221183	608.15	313899	629998	812.55	70697	205479	1176.71
1989	132599	193459	590.68	308437	632920	830.78	73912	215300	1179.32
1990	118668	169382	577.88	310069	596723	779.14	79091	213411	1092.43
1991	111578	153847	558.23	310190	627322	818.78	85250	237868	1129.65
1992	121463	164089	546.94	310646	647663	844.09	89520	253442	1146.20
1993	95307	133207	565.86	298601	619496	839.94	85247	218779	1039.03
1994	85508	146194	692.19	302475	577792	773.37	91520	232101	1026.75
1995	103754	161753	631.18	307087	559323	737.40	70368	186343	1072.11
1996	120545	189652	636.96	302119	558353	748.23	97640	295614	1225.75
1997	108453	153693	573.74	310908	624152	812.76	93356	279733	1213.12
1998	84485	107280	514.09	296383	578076	789.65	90968	251088	1117.48
1999	89532	125550	567.73	308493	677330	888.91	93475	295980	1281.95
2000	88761	122050	556.70	308790	653440	856.73	97502	302287	1255.19
2001	88659	129980	593.55	309640	706326	923.53	100075	319360	1291.99
2002	91012	133976	595.98	310660	684922	892.60	100419	338349	1364.12
2003	91824	144635	637.71	314433	704621	907.26	100375	350339	1413.08
2004	87577	140194	648.10	309692	658888	861.36	104870	360921	1393.36
2005	101655	168998	673.06	285861	638938	904.91	108440	386395	1442.60
2006	109320	186679	691.35	306489	706204	932.86	107700	386884	1454.35
2007	120577	218098	732.30	312705	575773	745.45	107070	381158	1441.25
2008	131986	230586	707.31	323413	717692	898.43	111179	471264	1716.11
2009	124312	215196	700.85	321903	701153	881.84	118495	465213	1589.48
2010	120478	226612	761.51	320495	707423	893.64	114533	467984	1654.26
2011	110430	192617	706.17	315618	723693	928.32	118705	491192	1675.27
2012	102094	182331	723.04	305567	709931	940.62	118782	485274	1654.01
2013	99482	171228	696.84	307837	741989	975.84	111697	447063	1620.43
2014	79968	149698	757.88	301512	704984	946.62	111080	463063	1687.75

Appendix 6: Cropping area, production & yield data of historical major crop of Greater Noakhali Region: pulse, groundnut & soybean

Year	Pulse			Groundnut			Soybean		
	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)
1985	25243	21992	352.72	11091	17346	633.19	31	47	613.82
1986	25125	20990	338.23	11231	17483	630.23	69	103	604.35
1987	23382	20095	347.94	11458	17791	628.63	112	181	652.98
1988	26481	21955	335.66	10728	17207	649.37	148	244	667.47
1989	27785	25732	374.94	11225	15876	572.61	361	562	630.28
1990	25183.5	21840	351.11	12474	18581	603.07	390	579	601.06
1991	25602	21807	344.85	11917	14438	490.50	427	586	555.61
1992	25953	22295	347.79	9794	11129	460.04	411	596	587.09
1993	26890	19820	298.41	13304	11505	350.11	571	677	480.02
1994	34442	25477	299.48	14127	18293	524.25	815	1071	532.03
1995	27468	25717	379.05	15120	20419	546.75	875	1421	657.49
1996	16759	21597.5	521.75	13587	17861	532.21	1072	1619	611.44
1997	14083	11811	339.54	22889	29599	523.54	1880	2963	638.08
1998	20041	17189	347.24	28073	39095	563.81	2988	4137	560.54
1999	23786	19699	335.29	23912	30097	509.58	2988	3975	538.59
2000	27736	23064	336.66	17725	24716	564.54	2372	3446	588.17
2001	28734	27468	387.02	14567	20844	579.31	2634	3922	602.83
2002	27205	28820	428.89	11681	17947	622.04	3541	4769	545.20
2003	30613	28809	381.00	12554	19194	618.99	4519	6772	606.71
2004	31456	34904	449.24	13279	20603	628.16	12752	17018	540.30
2005	30537	33132	439.26	19350	32518	680.37	23436.5	35032	605.16
2006	31199	34202.5	443.83	20529	34144	673.36	31634	47445	607.21
2007	37760	33375	357.84	27519	41317	607.85	41504	63596	620.36
2008	39187	30997	320.24	29188	45754	634.64	41522	61610	600.73
2009	45777	43158	381.70	22724	36398	648.48	43256	63938	598.43
2010	32650	32161.4	398.80	31119	52113	677.99	48523	82332	686.95
2011	33119	32893.2	402.10	30948	50797	664.52	53814	83812	630.54
2012	52060	49701.2	386.51	24772	42493	694.48	54953	87627	645.58
2013	53366	60868	461.77	18356	23236	512.49	60761	82353	548.73
2014	58392	67415	467.42	17866	27990	634.28	59274	95784	654.23

Appendix 7: Cropping area, production & yield data of historical major crop of Greater Noakhali Region: winter Vegetables, sweet potato & green chili.

Year	Winter Vegetables			Sweet Potato			Green Chili		
	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)
1985	5502	64726	4762.79	5862	69404	4793.38	11489	9126	321.59
1986	5757	67797	4767.79	5738	68100	4804.96	11091	8927	325.87
1987	5467	67587	5005.15	5693	72598	5162.81	10536	8908	342.30
1988	5998	69880	4716.82	5342	63403	4805.17	11391	8913	316.79
1989	6671	61431	3728.20	5475	69994	5175.83	12180	8575	285.03
1990	6301	66697	4285.48	5968	70610	4790.05	11927	7749	263.04
1991	6808	72503	4311.61	5938	65437	4461.55	10558	7538	289.05
1992	7162	84062	4751.91	5721	69566	4922.98	9915	9678	395.18
1993	6490	59754	3727.57	6029	40718	2734.29	7765	4360.4	227.35
1994	6602	72676	4456.75	6768	66679	3988.70	7490	3074.7	166.20
1995	6148	71936	4737.13	6378	77110	4894.74	7403	5482	299.80
1996	5585	71107	5154.57	5493	60620	4467.96	8916	4898	222.41
1997	7086	79686	4552.86	3960	49121	5021.98	7183	5099	287.40
1998	8336	96215	4672.92	6771	87115	5208.87	6695	5779	349.47
1999	6936	85043	4964.01	4452	66592	6055.78	7158	6612	373.98
2000	7720	91216	4783.62	5903	87446	5997.50	6752	7212	432.44
2001	7730	127274	6665.97	5470	82067	6074.13	6309	7960	510.81
2002	8312	140505	6843.67	5630	90797	6529.29	7140	9128	517.58
2003	8430	152934	7344.79	5493	89450	6592.86	8724	12079	560.56
2004	7642	131286	6955.28	5769	108338	7602.97	8736	11798	546.76
2005	9375	144923	6258.48	5259	85738	6600.45	8565	10610	501.52
2006	10510	167226	6441.75	5021	90166	7270.36	7230	7818	437.78
2007	10283	154962	6101.10	5076	71221	5680.54	7760	10149	529.50
2008	10839	169911	6346.52	5083	71273	5676.86	8556	11165	528.31
2009	11005	153365	5642.08	2084	30016	5831.20	8433	11623	558.01
2010	11460	193197	6825.25	5217	73206	5681.05	6591	8332	511.80
2011	12651	202277	6473.28	4663	58895	5113.47	6749	8855	531.19
2012	13757	222704	6554.01	8333	105027	5102.73	6645	9078	553.09
2013	14271	239466	6793.48	8113	108102	5394.55	5795	7426	518.81
2014	15061	274234	7371.75	7718	115261	6046.17	6284	9518	613.21

Appendix 8: Cropping area, production & yield data of historical major crop of Greater Noakhali Region: mustard & wheat.

Year	Mustard			Wheat		
	Area (ha)	Production (MT)	Yield (kg/acre)	Area (ha)	Production (MT)	Yield (kg/acre)
1985	1593	1347	342.34	2208	3062	561.45
1986	1399	1170	338.59	2031	2875	573.10
1987	1845	1678	368.21	2086	2756	534.89
1988	1454	1334	371.44	1995	2866	581.62
1989	1231	765	251.60	2157	3467	650.74
1990	1165	990	344.04	1681	3279	789.73
1991	950	675	287.66	1245	1934	628.91
1992	1172	880	303.99	1103	1793	658.12
1993	833	678	329.52	1089	1805	671.05
1994	992	836	341.19	950	1400	596.63
1995	1230	1050	345.61	1283	2009	633.95
1996	846	558	267.03	940	1459	628.39
1997	712	468	266.11	1449	2379	664.71
1998	1029	824	324.20	1695	2877	687.18
1999	1083	828	309.53	2115	3017	577.52
2000	1098	890	328.16	1283	2155	680.02
2001	838	779	376.35	982	1609	663.36
2002	333	291	353.80	297	365	497.55
2003	358	245	277.07	494	765	626.96
2004	634	606	386.98	436	817	758.65
2005	700	621	359.17	555	956	697.38
2006	718	717	404.29	456	929	824.81
2007	953	875	371.72	312	577	748.73
2008	835	710	344.25	525	1073	827.45
2009	634	520	332.06	364	771	857.54
2010	324	279	348.63	207	436	852.75
2011	595	556	378.32	223	462	838.76
2012	742	727	396.67	175	367	849.05
2013	1181	1222	418.91	180	419	942.42
2014	2404	2779	468.01	176	367	844.22

Appendix 9: The questionnaire of farmer households' survey

PART 1: BASIC INFORMATION OF RESPONDENT (HOUSEHOLD)

1.1 Date of Interview: __/__/__ __

1.2 Type of Respondent: ☐ Rice Farmer, ☐ Non-Rice Farmer, ☐ Mixed;

1.3 Location of Farm: District ……………………, Thana ……………………………,

Union ………………………., Village …………………………………………..,

1.4 Geographical Information: Longitude …………………………………………….,

Latitude …………………………………………….....

1.5 Name of Respondent: ………………………………………………………...;

1.6 Is the respondent head of household? ☐ Yes, ☐ No;

1.7 Age: ………….. Years;

1.8 Farming Experience: …………Years;

1.9 Gender: ☐ Male, ☐ Female;

1.10 Household size/Number of family member: ☐

1.11 Educational Qualification: ☐ MA/MSc, ☐ BA/BSc, ☐ HSC, ☐ SSC,

☐ Primary, ☐ Literacy, ☐ None; (Total year of schooling: ………. years)

1.12.1 Main occupation:

1.12.2 Secondary occupation:

1.13 Household yearly total income (Tk):

Income from agricultural activities		Income from non-agricultural activities	
Items	Income (Tk)	Items	Income (Tk)
Rice		Business	
Other Crops		Job	
Fishery		Remittance	
Livestock		Pension	
Fruits & homestead garden		Other income from non-agriculture (if any)	
Other income from agriculture (if any)			
Sub-Total		Sub-Total	

1.14 Household Yearly Expenditure (Tk.): ……………………………………………

1.15 Household assets (Tk): …………………………………………………………..

Items	Quantity	Market price (Tk)
Television		
Refrigerator		
Mobile phone		
Radio		
Motor cycle		
Bicycle		
Furniture		
Other (specify)		

1.16 Tenure Status: ☐ Yes, ☐ No;

1.17 Livestock (cow, goat, sheep, buffalo, etc.) ownership: ☐ Yes, ☐ No;

PART 2: FARM INFORMATION

2.1 Farm Type (tenancy): ☐ Owner Operator, ☐ Owner cum Tenant, ☐ Pure Tenant

2.2 Total Land (ha): ☐ High land, ☐ Medium high land, ☐ Medium low land, ☐ Low land, ☐ Total;

2.3 Soil Type: ☐ Clay, ☐ Clay-loamy, ☐ Loamy, ☐ Sandy, ☐ Other (specify);

2.4 Irrigation Facilities: ☐ Irrigated land, ☐ Rainfed/Non-irrigated Land, ☐ Both;

2.5 Source of Irrigation: ☐ Surface water irrigation, ☐ Ground water irrigation;

2.6 What is the source of your seeds? ☐ Own, ☐ Neighbour, ☐ BADC, ☐ Dealer, ☐ Other (Specify);

2.7 What type of fertilizer do you use now?

(i) Organic: ☐ Urea, ☐ Compost, ☐ Cowdung, ☐ Other (specify), ☐ None;

(ii) Inorganic: ☐ TSP/DAP, ☐ MOP, ☐ Gypsum, ☐ Zinc, ☐ Other (specify), ☐ None;

2.8 What type of fertilizers did you use 20-30 years before?

………………………………………………………………………………………;

PART 3: ACCESS TO AGRICULTURAL EXTENSION SERVICES & INSTITUTIONAL FACILITIES

3.1 Do you have access to agricultural extension services? ☐ Yes, ☐ No;

If yes, then from which source? ☐ Government, ☐ NGO, ☐ other (specify);

3.2 Do you get extension services from other neighboring farmers? ☐ Yes, ☐ No;

3.3 Do you get any, in advance, climatic (e.g. temperature, rainfall, droughts) information from any sources? ☐ Yes, ☐ No;

If yes, then from which source? ☐ Radio, ☐ Television, ☐ Newspaper, ☐ Agriculture Office, ☐ Other (specify);

3.4 Do you have access to agricultural credit of government organization or NGO?

☐ Yes, ☐ No;

3.5 Do you get any agricultural subsidy from government (input, cash subsidy, etc.)?

☐ Yes, ☐ No;

3.6 Do you have access to electricity at home? ☐ Yes, ☐ No;

3.7 Where do you sell your agricultural product? ☐ Local market, ☐ Urban market;

Distance to local market: ……….km; Distance to urban market: …………km;

Sell to local market: ………. %; Sell to urban market: ………. %

PART 4: CROPPING PATTERN

(A) Present cropping pattern:

4.1 What are the name of crops did you grow last year (2014) according to growing season?

SL No.	Cropping pattern	Area coverage (ha)		Major crop (ha)			Yield of crops (t/ha)		
				Rabi (Mid Oct-Mid-March)	Kharif I (Mid March-Mid July)	Kharif II (Mid July-Mid Oct)	Rabi	Kharif I	Kharif II
1			1a						
			1b						
			1c						
2			2a						
			2b						
			2c						
3			3a						
			3b						
			3c						

4.2 According to your opinion, what are the major cropping patterns in your area now?

a)……………………………………………………………………………….;

b) ………………………………………………………………………………;

c) ………………………………………………………………………………;

(B)Past cropping pattern:

4.3 According to your knowledge, what were the major cropping patterns 30 years before?

a) ……………………………………………………………………………..;

b) ……………………………………………………………………………..;

c) ……………………………………………………………………………..;

PART 5: CAUSES OF CROPPING PATTERN CHANGE

5. What are the major causes of cropping pattern change in this area according to your opinion? ☐ a) Climate Change, ☐ b) Non-Climatic Factor, ☐ c) Both;

[If answer is a, go to question of part 6; if answer is b, then part 7 and if answer is c, then answer question of both part 6 &7]

PART 6: (A) Perception about climate change:

6.1 Do you think climate is changing in your area? ☐ Yes, ☐ No;

6.2 Is the climate warming over the last 30 years? ☐ Yes, ☐ No;

6.3 Is there any change of drought (dry) period? ☐ Increase, ☐ Decrease, ☐ No change;

6.4 Is there any change in sunshine duration over the last 20-30 years?
☐ Increase, ☐ Decrease, ☐ No change;

6.5 Has there been any change in rainfall pattern (intensity, quantity & time) in compared to 20-30 years back? ☐ Yes, ☐ No; (if yes what type of change)

………………………………………………………………………………………;

6.6 What is your understanding on the occurrence of natural calamities/disasters in the past 30 years? ☐ Increasing, ☐ Decreasing, ☐ Same/No change;

6.7 What type of disasters do you usually face in your locality? ....;

6.8 What is your idea on the occurrence of tropical cyclone in the past 30 years?
☐ Increasing, ☐ Decreasing, ☐ No change;

6.9 What is your idea on the occurrence of flood in the past 30 years?

☐ Increasing, ☐ Decreasing, ☐ No change;

6.10 What is your idea on the occurrence of drought in the past 30 years?

☐ Increasing, ☐ Decreasing, ☐ No change;

(B) Cropping pattern choices & climate change (in relation to salinity & water logging problem):

6.11 What is the most significant climatic hazard in your locality in crop agriculture?

☐ Drought, ☐ Flood, ☐ Salinity, ☐ Water logging, ☐ Other (specify);

6.12 Is there any salinity problem in your locality? ☐ Yes, ☐ No;

6.13 If yes, what is your opinion about salinity change in your locality?

☐ Increasing, ☐ Decreasing, ☐ No change;

6.14 Does salinity affect your cropping pattern choices? ☐ Yes, ☐ No;

6.15 If yes, what have you done in such cases? ☐ Change crop variety or introduce saline tolerant variety, ☐ Shifting growing season, ☐ Do nothing;

6.16 In which season, salinity affects most? ☐ Pre-monsoon, ☐ Monsoon, ☐ Post-monsoon, ☐ Winter;

6.17 Is there any water-logging problem in your locality? ☐ Yes, ☐ No;

6.18 If yes, what is your opinion about water-logging problem in your locality?

☐ Increasing, ☐ Decreasing, ☐ No Change;

6.19 Does water-logging problem affect your cropping pattern choices? ☐ Yes, ☐ No;

6.20 If yes, what have you done in such cases? ☐ Change crop variety or introduce flood tolerant variety, ☐ Shifting growing season, ☐ Innovative farming like floating bed, ☐ Grow nothing in the period;

6.21 In which season, water-logging affects most? ☐ Pre-monsoon, ☐ Monsoon, ☐ Post-monsoon, ☐ Winter;

6.22 Have you faced any new disease in your crop production? ☐ Yes, ☐ No;

.23 What climatic variables affect your crop production most? ☐ Temperature, ☐ Rainfall, ☐ Humidity, ☐ Sunshine Duration, ☐ Other (specify);

6.24 Is there any crop which you did not plant 30 years ago, planting now?

☐ Yes, ☐ No; if yes, please mention ....;

6.25 Is there any crop which you did plant 30 years ago, not planting now?

☐ Yes, ☐ No; if yes, please mention ....;

6.26 Is there any change in cropping season, planting and harvesting?

☐ Yes, ☐ No; if yes, what type of change? ....;

6.27 Have you planted any cash crops by reducing food crops? ☐ Yes, ☐ No;

If yes, what? ....;

And why? ....;

PART 7: NON-CLIMATIC FACTORS

7.1 In your opinion, what are the causes of changing cropping pattern over the period other than climate change? ☐ Changed demand for food crops, ☐ Reduced water availability, ☐ Introduction of high yielding varieties, ☐ Expansion of agricultural education, ☐ Increased Govt. Support, ☐ Development of entrepreneurship, ☐ High Profitability, ☐ All above, ☐ Other;

7.2 If answer is other, please mention important two or three reasons:

a) ……………………………………………………………………………;

b) ……………………………………………………………………………;

c) …………………………………………………………………………….;

PART 8: ADAPTATION MEASURES

8.1 Have you taken any adaptation measures due to climate change in order to reduce adverse impacts? ☐Yes, ☐No; If yes, go to question 8.2, 8.3 & 8.4, if no, 8.5.

8.2 What type of adaptations have you taken in crop management & farming practices?

Adaptive Means/Option	Please put 1 for main option and tick (✓) mark for others that you exercise
Shifting of growing season (Changing planting date)	
Introduction of climate-tolerant (saline, drought & flood) varieties	
Innovative farming practices like mulching, floating bed, etc.	
Short duration crop	
Farming of non-rice crops	
Excavation of pond/ canal & drainage improvement	
Agro-forestry and homestead gardening	
No adaptation	

8.3 Do you have any other local/indigenous adaptation measure beside above measures?

☐ Yes, ☐ No; if yes, please mention ……………………………………….;

8.4 When you are performing any or some of the aforementioned adaptive means, what other adjustments you normally make (i.e., adapt to adaptation)?

Adapt to adaptation	Please put 1 for principal adjustment and tick (✓) mark for others that you perform
Institutional micro-credit	
Spending from past saving	
Loan from rural usury	
Sale of crops & livestock	
Sale and mortgage of some land	
Sale of other assets	
Migration to other areas especially cities	
Others	

8.5 What are your difficulties/barriers in taking adaptation measures?

Barriers/difficulties to adaptation	Please put 1 for main barriers and tick (√) for others that you face
Lack of information about potential climate change	
Lack of adequate irrigation facility	
Lack of knowledge concerning appropriate adaptation	
Lack of credit/money/saving	
Lack of own land	
Labor shortage in need	
Lack of storage facilities	
Other (specify)	

8.6 In your opinion, what kind of Govt/NGOs interventions are needed to cope up with risks involved in cultivating crops to address climate change? ……………………..
…………………………………………………………………………………….;

Date: ....

____

Signature of the Interviewer